S

STELLINGEN

behorende bij het proefschrift

SUPPORTING FLEET MANAGEMENT BY MOBILE COMMUNICATIONS

Peter R. Schrijver

11 oktober 1993

I

Het gebruik van real-time informatie in een planningsproces voor de operationele besturing van een bedrijfsproces waarvan de uitvoering beïnvloed wordt door onvoorziene en niet te beheersen verstoringen levert slechts een beperkte verbetering van de effectiviteit en efficiency van het te besturen bedrijfsproces op.

Dit proefschrift

II

Bij het stimuleren van technologische ontwikkelingen binnen het transport is een discrepantie zichtbaar tussen de mogelijkheden die de technologie biedt en het daadwerkelijk toepassen van deze technologie door bedrijven. Pilot-projecten, die uitgevoerd worden om de mogelijkheden van nieuwe technologieën te demonstreren, kunnen niet in voldoende mate bijdragen aan het verkleinen van deze kloof. Het verdient derhalve aanbeveling pre-competatieve samenwerkingsverbanden in het leven te roepen waarin naast overheid, branche-organisaties, vervoerders en advies-bureaus ook leveranciers van hardware, software en communicatiesystemen zitting hebben.

III

De invoering van nieuwe informatietechnologieën binnen het wegtransport, zoals mobiele communicatie, wordt belemmerd door het feit dat vervoerders de baten die invoering met zich meebrengt vooraf niet of nauwelijks kunnen vaststellen. Het vaststellen van deze baten kan in de praktijk slechts na invoering van de nieuwe technologie plaatsvinden. Een *dynamisch-modelleren*-aanpak is veelbelovend om deze impasse te doorbreken.

H.G. Sol, *Schuivende Grenzen rond Technische Bestuurskunde*, Inaugurele rede Technische Universiteit Delft, 1992.

IV

De invoering van een *snelheids*begrenzer op vrachtwagens zal slechts een positieve invloed op de verkeersveiligheid hebben als de vrachtwagen tevens wordt uitgerust met een *rijtijd*begrenzer. De invoering van deze begrenzers zal overigens een aanzienlijke negatieve invloed hebben op de stiptheid waarmee een transportbedrijf de transporten kan uitvoeren.

V

Het veelvuldig gebruik van voorbeelden uit de transportbranche voor het demonstreren van mogelijkheden van onder andere modelleringstechnieken doet vermoeden dat het toepassen van informatietechnologie binnen de transportbranche een voorbeeldfunctie heeft, hetgeen niet strookt met het resultaat van de meeste automatiseringsprojecten die in deze branche zijn uitgevoerd.

P.W.G. Bots, *An Environment to Support Problem Solving*, Proefschrift Technische Universiteit Delft, 1989

P. Coad and E. Yourdon, *Object-Oriented Analysis* (2nd edition), Prentice Hall, Englewood Cliffs, 1991.

VI

Het hanteren van het principe "de vervuiler betaalt", in een poging de hoeveelheid gestort afval te beperken, zal uiteindelijk resulteren in een verhoogde hoeveelheid ongecontroleerd, illegaal, gestort afval.

VII

Gezien de toenemende congestie op het Nederlandse autosnelwegennet verdient het, in het kader van een meer rationele verkeersregelgeving, aanbeveling de aanduiding "*knoop*punt" te vervangen door "*knel*punt".

VIII

Het is tekenend voor de huidige drukte in de treinen dat conducteurs van de Nederlandse Spoorwegen bij controle niet langer om een "plaatsbewijs" vragen maar in plaats daarvan een "vervoersbewijs" verlangen.

IX

De omvang van recentelijk gebouwde ministeries lijkt in schril contrast te staan met het voornemen van de Nederlandse overheid het overheidsapparaat af te slanken.

X

Het gebruik van afbeeldingen van bergsporters in advertenties van automatiseringsbedrijven geeft een goede afspiegeling van de risico's die het uitvoeren van automatiseringsprojecten kenmerkt.

SUPPORTING FLEET MANAGEMENT

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Proefschrift

ter verkrijging van de graad van doctor
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door

Peter Ronald Schrijver

informatica ingenieur

geboren te 's-Gravenhage

Dit proefschrift is goedgekeurd door de promotor:

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For my parents
and
For Monique

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CONTENTS

PREFACE

Communications play an important role in road transport nowadays. Trucks, the means of production, generally operate throughout a geographically dispersed area, and dispatchers are dependent on reliable communications with the drivers to instruct them adequately and to obtain useful information on the trip progress.

Mobile communication is a communication medium that provides two-way instantaneous communications between dispatchers and drivers, providing an opportunity for both dispatchers and drivers to make contact with each other at virtually any time and any place. Recent developments in mobile communication technology have made mobile communications available to the greater part of the road transport industry. This dissertation investigates the possibilities mobile communications have to support the daily tasks of road haulage dispatchers. It focuses on the development of an information system that incorporates mobile communication technology and on establishing the benefits of using such an information system.

Many people and many companies have contributed to the achievement of this dissertation, directly or indirectly. First of all, I would like to thank Henk Sol for providing me with the opportunity to write this dissertation under his supervision, for monitoring the processes that have lead to this dissertation, and for his valuable advice.

Thanks are due to Koninklijk Nederlands Vervoer for supporting my research over the last four years. Special thanks go to my colleagues at the "Technische Zaken" department for providing a pleasant and stimulating environment to work in. Especially, I would like to thank Simon Huiberts for the numerous discussions we had and for the valuable criticisms he made.

For the development of the *FMS prototype*, I am indebted to the Dutch Ministery of Transport, Public Works, and Water Management who provided a subsidy that enabled the development of a prototype Fleet Management System, in co-operation with Incontrol Management Consultants. Thanks go to Frits Huiskamp, Jack Monnereau, and Jan Sepp for showing their interest, for their involvement in the FMS project, and for the work they did.

I thank the haulage companies involved in our research for their co-operation and their willingness to have real-life tests performed at their planning departments. Furthermore, I would like to thank all dispatchers and drivers that were involved in these real-life tests.

Several people originating from the academic world contributed to this dissertation. I would like to thank the "Kongsi" society for sharing the pleasant and difficult moments in writing a dissertation, and the "OASIS" society for the interesting discussions on organizational aspects of information systems. Special acknowledgements go to the four students who did an excellent job in developing and implementing the RTT simulation model: Martijn Babeliowsky, Jurriën Blik, Ellen Metaal, and Stas van der Schaaf.

Finally, I would like to thank two people who contributed a great deal to the actual appearance of this dissertation: Danny Otto for the colourful and beautiful cover design, and Miranda Aldham-Breary for correcting the many mistakes I made in using the English language.

Last, but not least, I wish to thank my family and partner. My parents have shown great interest and have encouraged me during the research. I thank Monique for her love and support and for reminding me of the value of *human* communications.

Zoetermeer
August 1993

Peter R. Schrijver

CHAPTER 1

BACKGROUND AND RESEARCH APPROACH

1.1 Introduction to Road Transport

Road transport is of considerable economic importance for the Netherlands. In 1989, the road transport industry contributed more than 8 percent of the gross national product, a relative increase of almost 7 percent over the past ten years. Furthermore, the road haulage companies own almost 60 thousand trucks and employ more than 90 thousand (KNV 1992).

One of the reasons why the road transport industry is such an important economic factor in the Netherlands is the presence of *mainports*. These mainports, i.e., the port of Rotterdam and the national airport Schiphol, form an important node in the overall *physical distribution* system for moving goods from origin to destination.

Physical distribution can be viewed as "the collective term for the series of interrelated functions (principally transport, stockholding, storage, goods handling and order processing) involved in the physical transfer of finished goods from producer to consumer, directly or via intermediaries" (McKinnon 1989, p. 1). Physical distribution forms an integral part of the *business logistics* chain. Business logistics is defined as "the process of planning, implementing, and controlling the efficient, cost-effective flow and storage of raw materials, in-process inventory, finished goods and related information from point of origin to point of consumption for the purpose of conforming to customer requirements" (Ballou 1992, p. 4). A schematic depiction of the business logistics chain is shown in figure 1-1.

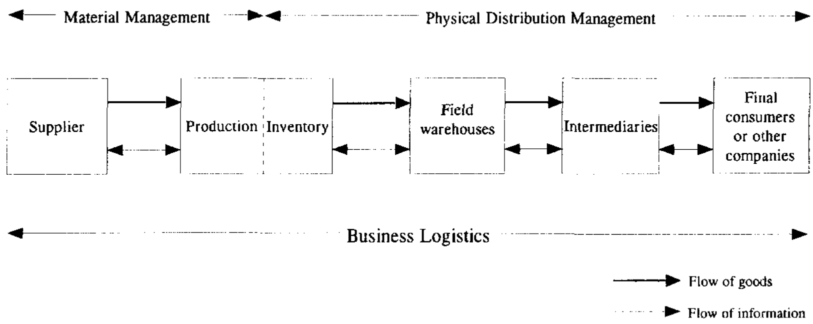

Figure 1-1 Business logistics

The business logistics chain is also built up from a *material management* function. Material management deals with all activities related to the movement of raw materials and semi-finished articles to the production process. After the products have been produced, they are stored to await transportation to the other nodes in the business logistics chain.

As can be seen from figure 1-1, there is both a "real" material flow through the business logistics system, and a flow of information between the different chains in the overall chain. This information flow establishes information exchange between the nodes in the business logistics chain, this is needed to control the business processes within one of the nodes. An important characteristic of this information flow is that information concerning the material flow is exchanged in two directions throughout the overall chain, whereas the material flow is only in the direction of the consumer.

As mentioned earlier in this section, road transport plays an important role within the physical distribution management part of the business logistics chain. Delivery of goods from shipper to consignee is mostly carried out using the road network.

Although the greater part of raw materials and semi-finished products is transported by rail or by waterway, road transport also fulfils an important function in the material management trajectory as a minor, but significant, part of the material stream is handled by trucks (KNV 1992).

The clear advantage of using trucks for the transport of semi-finished articles and products is the flexibility of delivering goods from door to door. Using trucks also has two major disadvantages. One, with flexibility, there comes a strong need for adequate transport planning. Two, using the road network introduces uncertainty due to the possibility of congestion, delays, and accidents.

It is also important to mention the human factor in the transport process. The driver is actually responsible for carrying out the deliveries. Drivers have to be motivated and needs to be instructed in an adequate way, because of the driver's autonomy. If this fails, a negative effect on transport performance may be seen.

1.2 Current Developments in Road Transport

Nowadays, hauliers have to contend with serious difficulties in their day-to-day operations. In this section, we will describe these difficulties and we will make a first step towards providing a feasible solution.

Over the past few years, a growing awareness of environmental issues has attracted a lot of attention from the public and the government. Road transport is responsible for 40 percent of vehicular air pollution (SVV 1988). One of the results of this has been the need to take drastic measures in the environmental area and reduce "empty-headed" or "deadheaded" distances, i.e., distances driven not loaded with any cargo, and improve the load factor of trips. The Dutch government, for instance, has set as goal to reduce the total distances covered by hauliers by 15 to 20 percent, whilst maintaining the present Dutch market share in international transport (SVV2 1990, p. 67). Although the measures intended by the government do not come into effect immediately, hauliers need to be prepared to meet future government demands and regulations.

Another problem the road transport industry has to cope with at present, is the increasing amount of traffic congestion. This trend is not only evident in the Netherlands, but is also apparent in the major conurbations of the rest of Europe. If adequate measures are not taken to prevent traffic growth, and therefore traffic congestion, traffic problems will escalate in the near future (McKinsey 1986, SVV 1988).

Hauliers have faced a serious decrease in profitability over the past five years. This decrease is a result of overall economic decline, strong competition between hauliers inside and outside the Netherlands, and increased labour, equipment, fuel, and overhead costs (NEA 1993). Profitability has fallen from 6.4 percent in 1986 to only 0.5 percent in 1992. The expectation for the next few years is that improvement will be very hard to achieve. Profitability in the road transport industry will probably decrease even further.

Another development that will affect hauliers' operations considerably is the deregulation of transport in the European Community ("Europe 1992"). The objective of this deregulation process is to realize an internal free trade market within Europe without regulatory, trade, or fiscal impediment. The progressive disappearance of regulatory impediment is a most important improvement for road hauliers. Customs formalities, within the European Community, are no longer required, resulting in less time spent at frontiers. Transportation within one foreign country (*cabotage*), i.e., transport within a foreign country from the country of origin of the transport combination, or between two foreign countries (*third-country transport*) will now be permitted.

Due to a general shift in industry from stock-driven production to order-driven production, there is a growing tendency for shippers to make more demands on the haulier (Bowersox *et al.* 1992). In the near future, the following five requirements will increasingly need to be met by the haulier (KNV 1990, p. 31):

1. *Reliability*. Shippers tend to make more precise arrangements for the time windows in which a shipment can be picked up or delivered. In this context, we define pick-up or delivery *punctuality* as the extent to which scheduled and actual times agree (Ballou 1992; De Jong 1992, p. 4).

2. *Frequency of transport*. The increasing application of innovative logistic concepts, such as "just in time," in production requires a transportation system that is able to ship smaller shipments at more frequent intervals (De Schepper 1991).

3. *Flexibility*. Shippers require a more flexible attitude from the haulier towards trip performance. Hauliers should be able to meet the even more demanding (ad hoc) requirements of the shippers. An example of this trend is the fact that the interval between acceptance and starting time of a transport order is becoming smaller.

4. *Rapidity*. Transports should be carried out as soon as possible and as fast as possible.

5. *Transportation costs*. Transports should cost as little as possible. Although this statement looks trivial, from an economic perspective it becomes increasingly important for a shipper to select a carrier that offers "value for money."

As a result of the requirements stated above the haulier is, to a growing extent, becoming a part of the *logistics chain* (Ruijgrok 1991, Vermunt 1993). The haulier makes a valuable contribution to the overall reliability and quality of the product via the flow of goods. As a consequence of this observation, the following conclusions can be drawn: (1) there is a necessity for change in the haulier's arrangement of business processes, (2) efficiency of transportation operations need to be enhanced, and (3) an improved mechanism for information exchange with the other parties in the logistics chain is demanded (Coopers & Lybrand 1990).

1.3 Fleet Management and Trip Execution

Having positioned road transport in the overall physical distribution system and having obtained insight into the difficulties that the road transport industry experiences, we will, in this section, further define road transport and zoom in on our problem areas.

As stated in section 1.1, there is a strong need for adequate scheduling of the transport when using trucks. In road transport, trucks perform the actual movement of goods through the physical distribution system. As can be concluded from section 1.2, managing and controlling trip performance are very important prerequisites for appropriate overall logistic chain management. Therefore, we will focus on these aspects of road transport.

The scheduling of trucks must be regarded as the primary task within a haulier's planning department. The objective is to carry out the requested transport orders in the most profitable way, satisfying customer demands while meeting government regulations. In the literature, this task is often referred to as *vehicle routing and scheduling*. Following De Jong and Sol (1991), we will use the term *trip planning* to address the issue of preparing an effective trip schedule. Throughout this dissertation, we regard the current way of planning trips by dispatchers as being "fixed", no modifications are made to the trip planning process except for the changes in information that is used to perform trip planning. The trip planning process as we see it in this dissertation can be more or less considered as a *continuous route planning* process (Stefanski *et al.* 1988). Transport orders come in, are registered, and are assigned to the truck most suited to the execution of the transport order. When assigning transport orders to trucks in this manner, on-line information about the current location, status, and destination of the trucks is needed.

Having determined the trip schedule, the relevant data and the transport orders are communicated to the driver, who can then begin to execute the trip. By *trip execution* we mean the process of delivering goods from origin to destination and all activities performed by the driver that are closely connected to the main transport process.

Whilst trip planning and the execution of the trip is considered an important process in road transport, managing and controlling trip execution also forms part of the transport process. Controlling the trip execution process requires the presence of mechanisms for *direct feedback* (In 't Veld 1981). Therefore, during the execution of the trip schedule it is important for the driver to provide information about current trip execution status to the dispatcher. One of the most important status messages the driver can pass on to the dispatcher is the message that he or she has fulfilled his current assignment and that he or she is ready to carry out a new assignment. This handling of status messages and the related control of trip execution will be addressed as *trip execution monitoring*.

A close interaction exists between trip planning and trip execution monitoring. To enable trip execution monitoring, data on trip schedules and transport orders are used. Important messages from drivers or the occurrence of deviations in the execution of the trip schedule can lead to *replanning* in the trip planning function, e.g., adjustments to the current trip schedule or the schedule just being prepared are made as a consequence of changes in the trip execution status.

While such a close relationship and interaction exists between the trip planning and trip execution monitoring functions, it is fairly difficult to make a sharp distinction between these two functions. In road transport practice, one will see that the individual tasks that build up these organizational functions are, most of the time, carried out in a random order by one dispatcher. Therefore, we will view the formation of the trip planning and trip execution monitoring functions as a combination and designate this combination of functions *fleet management*. In this context, the fleet may be defined as the haulier's rolling-stock that is involved in trip execution.

Fleet management can be defined as follows:

> *Real-time planning, monitoring, and controlling of fleet movements and operations aimed at minimizing operating costs and satisfying customer demands*

This definition is in agreement with the definition of "fleet management in a narrow sense," i.e., performing continuous monitoring and controlling of the trip execution process, given by Francke and Huiberts (1989). The latter definition does not involve, however, the planning activity, while our definition expresses the strong cohesion between the planning, monitoring, and controlling processes when operating on a real-time basis.

The interaction between fleet management and trip execution can be modelled using the *information paradigm* put forward by Brussaard and Tas (1980). This paradigm states that a system, e.g., (a part of) an organization, can be abstracted as an *information system (IS)* and a *real system (RS)*. The information system monitors and controls the system's primary process contained in the real system. This monitoring and control process is realized by exchanging messages between the RS and IS component. The RS sends messages concerning its state to the IS, which looks at the messages and sends, if necessary, a response to the RS. This response message can cause the RS to change its state.

In figure 1-2, an *RS/IS-schema* is presented for the combination of fleet management and trip execution. The decomposition depicted presents fleet management as the information system and trip execution as the real system. Fleet management generates trip instructions that are sent to trip execution. Information about trips is returned to fleet management during trip execution. This information is used for making changes in the composed trip plan or is used for later general management reporting.

Due to the position of the trip execution process in the overall logistics chain, status requests from customers should be replied to and appropriate information about trip execution status should be forwarded to the customer. It is also possible, and some times desirable, to inform the customer about the trip execution status even when this has not been requested explicitly.

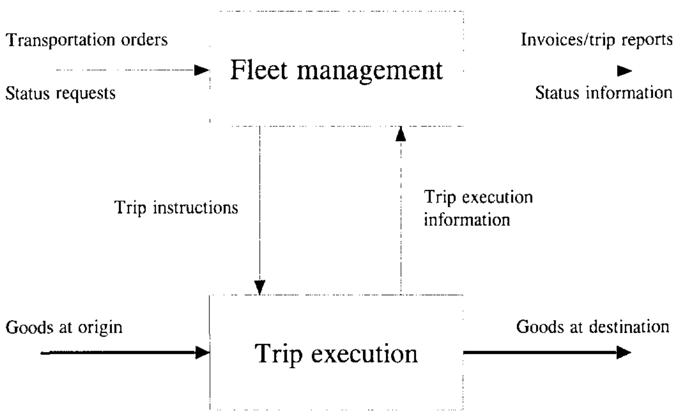

Figure 1-2 Fleet management and trip execution

During exchange of information between dispatcher and driver some serious problems can be encountered, because drivers and trucks are operating throughout a geographically dispersed area. Telephone is usually the communication medium that is used nowadays for passing on trip instructions or trip execution information. Using this communication system has some major disadvantages:

- Dispatchers are forced to be passive, i.e., dispatchers are not able to give trip instructions to or request information from the drivers every time contact between driver and dispatcher is required. As a consequence, the dispatcher has no possibility of making an adjustment in an assignment once the instructions for the assignment have been communicated to the driver.

- As incoming telephone calls generally have to be answered when they come in, the dispatcher's activities are very frequently interrupted.

- The driver's discipline is not very high, and he or she is often regarded as the "cowboy of the road." Due to this, trip status information is often incorrect or incompletely known by the planning department.

- There exists no possibility for the drivers to communicate trip status information to the planning department if the driver is unable to reach a telephone when a specific incident occurs. Examples of such incidents are when the driver is in a traffic jam, there is no (public) telephone nearby or when he or she is unable to obtain permission to use an available telephone at, for instance, a loading or unloading location.

From section 1.2, it is clear that the road transport industry faces an hostile, complex, and turbulent environment, which imposes heavy demands on organizations. These demands will cause organizational information acquisition to be more continuous and to be more wide-ranging (Huber 1984, p. 933). When, in addition, decision making is assumed to be the central organizational activity, one can conclude that providing adequate information for facilitating organizational decision making is essential for an organization (Huber and McDaniel 1986).

As we have shown in this section, a major part of the problems in organizational information acquisition in haulage companies stems from deficient communications between dispatcher and driver. Improving communications should lead to better availability of organizational information, allowing more frequent and faster decision making, as is required by turbulent environments. One of the methods for providing more timely, and efficient information is to employ *advanced communication and computing technologies* (Huber 1984, pp. 934-935).

Mobile communications is one of the means that can be applied for improving the current way of communicating between dispatcher and driver, due to technological developments, mobile communications has come within reach of a substantial part of the road transport industry, and the road transport industry has become aware of the positive effects mobile communications can probably have (KNV 1990, pp. 32-33). The Dutch government has attempted to stimulate the introduction of this kind of technology by providing subsidies for innovative projects in this field of interest (TVV 1990).

Mobile communication technology is one of the technologies that can be regarded as belonging to the area of *telematics*, the contraction of the terms "informatics" and "telecommunications." Telematics covers a broad range of applications which have in common that information is exchanged via computer systems between humans and/or computers *at a distance*. We emphasize that is necessary for the sender and the receiver of the information to be geographically separated from each other before it is appropriate to talk about telematics. Although mobile communications in itself is only a means of communication, we regard it to be part of the field of telematics as mobile communication technology will eventually be incorporated into existing computer systems.

It is strongly believed that the use of telematics will contribute to solving the current problems in road transport. Much research has been carried out in this field to investigate opportunities for telematics and to determine possible applications for telematics (Coopers & Lybrand 1990, NDL 1989, Tanja and Smook 1989, Van Duuren and De Roover 1991, Van Egeraat *et al.* 1991, Warschauer *et al.* 1991). The use of telematics in road transport is heavily stimulated by government, both at national and European level (DRIVE 1991, RVW 1993, TVV 1990).

In this dissertation, we will direct our attention to investigating the possibilities mobile communications can have to improve performance of fleet management operations in the road transport industry. Emphasis is given to determining the effectiveness of using mobile communications for fleet management and to establishing the integration with the business processes of the haulage company. As a starting-point for our research, we assumed that mobile communications were available to the road transport industry on a reliable and continuous basis and that it enabled timely and adequate information exchange between dispatchers and drivers. We will show in chapter 2 that systems providing such a mobile communications service exist, thus we will not consider the technical requirements a mobile communications system must meet when developing applications for the road transport industry.

In section 1.4, this general research objective will be elaborated and a research question will be presented. A further introduction to mobile communications will be given in section 2.5.

1.4 Research Questions

The description of the co-ordination mechanism for communication between dispatchers and drivers, given in section 1.3, indicates that problems exist in obtaining sufficient insight into trip execution status and therefore there is a lack of sufficient control of the trip execution process. Furthermore, the dispatcher has too few opportunities to intervene in the trip execution process.

In our opinion, this assertion holds especially for *professional* road transport opposite to *company* road transport. Therefore, we will restrict ourselves in our research to providing solutions to the problems found nowadays in fleet management within professional road transport. In this stage of our research, we are not able yet to specify and quantify the mentioned problems in full detail. From the conclusions drawn earlier in this chapter and personal observations from a number of Dutch hauliers, however, we find it legitimate to talk about *problems* in fleet management. Furthermore, as we have demonstrated, there are opportunities for improvement of fleet management performance. In line with Smith (1989), we regard the presence of opportunities for improvement of a business process as if the organization had to cope with a problem in the relevant business process.

Our restriction to the professional road transport area is suggested by the following considerations (Van Goor *et al.* 1989, pp. 196-197):

- Professional road transport is dependent on transport orders of customers who are not affiliated to specific hauliers. Therefore, the incoming flow of orders is less predictable and has a more distinct stochastic character.

- Professional road transport is able to achieve a high degree of efficiency through consolidation of transport orders, smoothing out temporary increases and declines in the incoming flow of orders, and the possibility of picking up return freight. Regulations do not allow company transport to pick up return freights.

- Professional road transport has to offer high quality services because it is operating in a highly competitive market.

- Professional road transport has to offer a high degree of customer service.

It has to be noted that in some cases the differences between professional and company transport are fading away. Especially, the last two points become more important in company transport.

Returning to co-ordination between fleet management and trip execution, we recall that in general there exists a discrepancy between the trip execution status as it is known at the planning department, the *perceived* trip execution status, and the *actual* trip execution status (cf., Beulens 1992). The reason for this discrepancy has already been discussed in section 1.3. It should be noted that a discrepancy also exists between the scheduled trip plan and the actual trip execution. This discrepancy is caused by the stochastic nature of the transport process and unforseen events that occur during trip execution. As a result, current trip execution status can not be determined from the scheduled trip plan. Therefore, regular status updates from the driver are necessary to provide the dispatcher with the information that is required for preparing the subsequent trip schedule.

We are of opinion that mobile communications can contribute to the driver sending more frequent, accurate, and timely trip status updates and that the technology will offer opportunities for the enhancement of control of the trip execution process. Thus, dispatchers will be provided with possibilities for improving the performance of the fleet management process.

Thus, we propose our main research question as follows:

> *Is it possible to improve the performance of the fleet management process in professional road transport business by the use of mobile communications?*

This main research question can be divided into three sub-questions, which we will try to answer. As a guideline for subdividing our main research question, we apply the three-level perspective on organizational performance introduced by Bots and Sol (1988). From a *micro*-perspective, attention is paid to task improvement of people in their work environment. In our case this leads to the question of how improvement of the dispatcher's tasks can be achieved using mobile communications. According to Sol (1988), "information workers can get considerable support in their task execution, supplemented with better co-ordination and communication." This implies that we have to design a new information system that is able to support dispatchers in the execution of their fleet management tasks. Consequently, our first sub-question will be directed to defining the "blueprint" of a new information system incorporating mobile communications:

1. *What are the characteristics of an information system that makes use of mobile communications for supporting the fleet management process?*

Once the blueprint for the information system mentioned above is determined, the question is raised what kind and magnitude of improvements can be expected when the dispatcher is offered support for the execution of his fleet management tasks. This brings us to our second sub-question:

2. *What are the effects of using mobile communications on the performance of the execution of the dispatcher's tasks?*

Until now, attention has only been paid to the micro-level task execution. When co-ordination between workplaces in an organizational setting is considered, organizational performance is addressed from a *meso*-level perspective. When we recall our main research question, looking from a meso-level perspective we are concerned with the performance of the trip execution process. Therefore, our third sub-question will be defined as follows:

3. *What are the effects of using mobile communications on performance of the trip execution process?*

In practice, we will restrict our research to investigating the effects of using mobile communications on organizational performance regarded from the micro- and meso-level perspective. If effects on organizational performance on a *macro*-level, i.e., the level where the organization is regarded as a single entity, happen to be a direct consequence of supporting the fleet management process in the planning department by using mobile communications, these effects will also be taken into account when evaluating our research questions.

To provide answers to the research questions stated above, it is necessary to select a research approach.

1.5 Research Approach

In the previous section, three research questions that were derived from our main research question concerning the use of mobile communications in professional road transport were formulated. To find an answer to these questions, a methodology and research approach have to be selected and applied.

In information systems research, several research strategies can be applied for investigating the research topic. Examples of these strategies are case studies, field studies, field experiments, and laboratory experiments (Benbasat and Nault 1990, p. 205). To answer our research questions, carrying out one or more case studies seemed to be most appropriate to us. Benbasat *et al.* (1987, p. 370) mention three reasons for selecting a case study approach in information systems research:

1. Information systems can be studied in a natural setting.

2. Emphasis is put on answering the "how and why" questions.

3. Case study research is an appropriate way to research an area in which little research has been carried out.

Due to the innovative character of applying mobile communications in professional road transport and the explicit necessity of carrying out the research in a natural setting, we believe that the three characteristics mentioned apply to our research area. The methodology we use during our research is based upon the research methodology applied by Van der Ven (1989), De Jong (1992), Hofstede (1992), and Verbeek (1991).

	Descriptive	Prescriptive
Empirical	Collection of data about and analysis of current situations (1)	Implementations of improved model (4)
Conceptual	Abstraction of the current situation (2)	Analysis and design of improved model (3)

Table 1-1 Overview of models used in research approach

The research methodology used during our research is derived from the *inductive-hypothetical model-cycle* (Sol 1982, p. 4). In this model-cycle, four model types can be distinguished, as presented in table 1-1. (The numbers are used to indicate the global order in which the models are specified.)

Initially, a trial using mobile satellite communications will be carried out by four Dutch hauliers to determine the feasibility of introducing this kind of new technology, to make a global estimation of the benefits that can be gained, and to determine the degree of acceptance by dispatchers and drivers. In the context of our research approach, the trial served as a preparatory investigation.

As a starting-point for actually applying our research, we take the fleet management process as it takes place nowadays. Thus, we need to analyze the existing situation and make a description of the actual fleet management process. Analyses of the existing situations within the planning departments of three hauliers are made, resulting in a description of the actual, "as-is", situation. These descriptions contain no normative elements and include specific details of the organization being described and will be referred to as *descriptive empirical models*.

Based on the three empirical models developed and common information about other hauliers, a *descriptive conceptual model* is constructed. This conceptual model is a description of the existing situation, but at a higher level of abstraction. Thus, the descriptive conceptual model can be viewed as "data void" (Bosman and Sol 1985, p. 82). The descriptive conceptual model provides global insight in the "as-is" situation, preserving the essential characteristics of the three empirical models, but omitting the unessential details of the existing situations.

At this point in our research methodology, there is a shift from developing empirical models describing an existing situation, whether or not at an abstract level, towards prescriptive models describing a future situation, which should contain solutions for the problems found in the empirical models. Analysis of the empirical models, conducting other investigations, literature research, and utilizing creativity will lead to a *prescriptive conceptual model.* This model contains normative elements and should present, in our case, changes to be made to the descriptive conceptual model, thereby utilizing the opportunities mobile communications offers. The prescriptive conceptual model should provide a solution for the problems identified in the descriptive conceptual model. The last step in our research approach is the shift to one or more *prescriptive empirical models*, comprising implementation of the changes proposed in the conceptual model. Experiments based on the prescriptive empirical models developed will be conducted within the three planning departments analyzed before.

Bosman and Sol (1985, p. 83) state that the purpose of constructing prescriptive conceptual models is to find a solution that is generally applicable. They recognize that this generality is mostly not achieved. Although we do not strive after a general applicable prescriptive conceptual model, by constructing *three* descriptive empirical models we will try to develop a prescriptive conceptual model that will provide a basis for other hauliers as well for developing solutions found in fleet management. We are, however, aware of the fact that generalization of the research findings is only allowable over the three case studies involved in the research.

To gain insight into the effects of using mobile communications in road transport, a simulation approach will be incorporated in the research approach described so far. This simulation approach will be followed to evaluate various alternatives and to estimate potential benefits of using mobile communications. The development of the simulation model was carried out in conjunction with the implementation of the prescriptive empirical models.

Finally, an evaluation of the overall research findings will be carried out as part of the research approach. Figure 1-3 presents the research approach that has been described in this section graphically.

The outline of this dissertation closely corresponds to the different steps distinguished in the research approach. Chapter 2 describes the development of information systems for road transport. This chapter also gives an introduction on the different, currently available, mobile communication technologies and evaluates the mobile communications trial. Chapter 3 presents the descriptive conceptual model for fleet management based on analyses of three planning departments. Chapter 4 presents the layout of a Fleet Management System (FMS) aimed at supporting the dispatcher in performing fleet management and incorporating both information system and mobile communication technology. Chapter 5 presents the results of the simulation study carried out to study the effects on trip execution performance if an FMS is applied. Chapters 6 and 7 describe the implementation of a prototype of the FMS and the results of actually applying this prototype in the three planning departments investigated. Finally, chapter 8 discusses the research findings and suggests directions for future research.

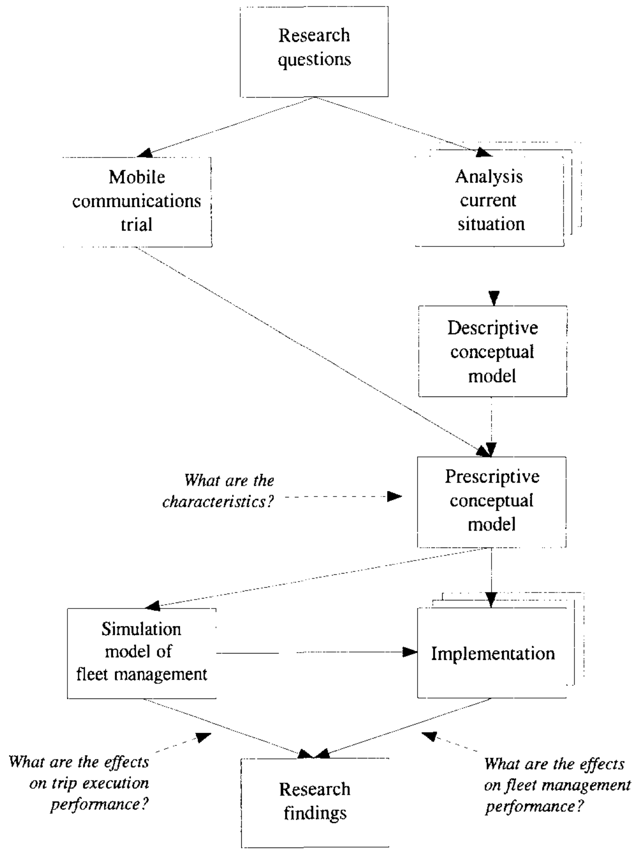

Figure 1-3 Applied research approach

CHAPTER 2

DEVELOPING INFORMATION SYSTEMS FOR ROAD TRANSPORT

2.1 Introduction

In chapter 1, we have outlined our field of interest, fleet management in professional road transport. Chapter 2 deals with general aspects of developing information systems for the road transport business. Emphasis is given to the question: how can information systems support fleet management?

Section 2.2 gives an introduction to problem solving theory and it introduces the various planning levels at which organizational decision making takes place. Special attention will be paid to the operational planning level in road haulage organizations, because fleet management takes place at this level. Section 2.3 deals with the development of information systems to support decision processes in general, whereas section 2.4 gives an overview of the efforts made so far with respect to developing information system applications for road transport.

An introduction to mobile communications and the different types of systems that can be distinguished in mobile communications will be given in section 2.5. Section 2.6 reports the results of the trial with mobile satellite data communications we carried out for our research.

2.2 Operational Planning in Road Transport

In decision making theory, a distinction is made between *well-structured* and *ill-structured* problems. A problem is called well-structured if it meets the following three requirements, and is called ill-structured if it fails on one or more of these requirements (Sol 1982, p. 5):

1. The set of alternative courses of actions or solutions is finite and limited.

2. The solutions are consistently derived from a model of the problem situation that shows good correspondence with reality.

3. The effectiveness or the efficiency of the courses of action can be numerically evaluated.

As we have argued in chapter 1, organizational decision making is the organization's central activity. In the context of distinguishing between well-structuredness and ill-structuredness of problems, organizational decision making should be regarded as solving *ill-structured* problems.

Fleet management is the key activity of a road haulage company's planning department. In our problem area we will view this as the central decision making activity. In addition, we claim that performing fleet management should be considered an ill-structured problem because of the following three reasons. One, when assigning transport orders to available vehicles and drivers in a certain order, a set of possible assignments can be constructed that is not limited in most cases. Two, due to the fact that there exists a discrepancy between the *perceived* trip execution status and the *actual* trip execution status and the uncertainty about future transport orders, we assume that the model of the problem situation does not correspond well to reality. Three, the effectiveness and efficiency of the fleet management process, and also therefore for alternative courses of action, are hard to establish due to the uncertainty about future transport orders and the softness of constraints put on the execution of transport orders.

A certain relationship exists between effectiveness and efficiency. Effectiveness can be viewed as being a measure of "goodness" of output, while efficiency is a measure of the resources required to achieve the output (Davis and Olson 1985, p. 287). In trip execution, effectiveness should be interpreted as to the extent trip execution is carried out correctly, and especially how far the requirements of the customers can be met. Effective fleet management should result in a trip schedule that allows for an effective and efficient trip execution. Efficiency is used with the meaning that no more resources are used than strictly necessary. Efficiency in trip execution deals with issues such as whether or not too much vehicle capacity is used for trip execution and whether or not too much distance is driven empty-headed. Efficiency in fleet management relates to the question if not too many resources are needed to perform the planning, controlling, and monitoring of the trip execution process.

In this section, we will also give a description of *planning*. Planning is a concept that has a close relationship to problem solving and decision making as described earlier in this section. Several definitions for the concept of planning are given in the literature. We favour the definition put forward by Boskma (1983, p. 18) and Takkenberg (1983, p. 28). They define planning as performing activities leading to a plan that comprises a coherent set of (intended) decisions and about the execution of certain activities in the future, aimed at the realization of certain objectives. Furthermore, planning is characterized by the fact that the planning process takes place before the actual execution of an activity. Therefore, planning can be regarded as "anticipatory decision making" (Ackoff 1970).

In organizations, several distinct levels can be identified at which planning takes place. Usually, four conceptual planning levels can be identified in a (large) organization, differing in the organizational level of responsibility, the scope of planning issues addressed, the degree of detail, and the planning horizon (Anthony 1965, Hirshfeld 1983). These planning levels are *strategic planning*, *tactical planning*, *operations planning*, and *scheduling and dispatching*. Fleet management should be placed at the scheduling and dispatching level. Hirshfeld (1983, p. 74) describes this level as "what specific operations or sequences of operations should be performed with existing facilities, or meet specified output requirements in the next operational period (for example, hour, day, week)?". When we apply this definition to our perspective on fleet management, fleet management can be formulated as dealing with determining which vehicles and which drivers should be assigned to which transport order or sequence of transport orders for the next operational period, usually one or two days in road transport.

Solving scheduling and dispatching problems within road transport has been given a lot of attention during the last two decades. Most of the efforts in solving *vehicle routing and scheduling* problems have been made within the Operations Research field, both in developing mathematical algorithms and in developing information systems for support of vehicle routing and scheduling (Bodin 1990, Golden and Wong 1992). Vehicle routing and scheduling problems deal with making decisions concerning the spatial configuration of vehicle movements, given demands for service at various points in a transport network the vehicles may use *(routing)* and concerning the times at which various locations are visited (*scheduling*) (Bodin *et al.* 1983, p. 67).

2.3 Information Systems to Support Decision Processes

In the last section, we have considered decision making, the organization's central activity, from an organizational perspective. Performing decision making requires the presence of *decision makers*, people that perform actual decision making at the distinct planning levels within an organization. We assume that decision makers in organizations follow a *satisfactory* way of decision making. This means that they limit the search for alternatives and accept the first alternative that satisfies all the problem constraints, rather than continue to search until a better one than the first acceptable alternative or the optimal alternative is found.

This assumption is based on the paradigm of *bounded rationality*. By the bounded rational behaviour of a decision maker, we mean that we do not presume that decision makers have all relevant information and an unlimited capacity to process this information. Decision makers within an organization operate in their own environment with their own definitions and limited scopes on accessible data (Simon 1960).

In the 1970s, several researchers in the information systems field suggested that supporting the decision maker rather then replacing him by some sort of automated planning system would be a worthwhile direction of research. These kinds of systems are traditionally called *decision support systems* (DSS), although there is no clear definition available of what is exactly contained in a DSS (Sprague 1980).

There is a growing awareness in the information systems field that only supporting ill-structured problem solving is not sufficient to improve organizational performance. Problem solving tasks performed by decision makers in organizations can be divided into two categories. Panko (1984) characterizes these categories as *Type I* and *Type II* tasks. Sol (1991, p. 121) provides a detailed overview of differences between these two types of tasks. Type I tasks are characterized by a large number of transactions which are executed at low cost, well-defined problems that should be solved, with an emphasis on determining *how* the tasks should be performed (process-orientation). Type II tasks are characterized by a small number of transactions which require a relatively high cost to be executed, ill-structured problems that should be solved, with an emphasis on determining *why* the tasks should be performed (problem-orientation).

As Sol (1991, p. 122) expects little value from refining the concepts of decision support systems and other information systems that support decision makers in organizations, he proposes to call all these kinds of systems *information systems to support decision processes* (ISDP). ISDPs provide integrated support for both Type I and Type II tasks of problem solvers, thereby integrating concepts from decision support systems, expert systems, computer supported collaborative work, etc. In the fast-moving field of information systems development, where systems are enhanced and new types of systems are invented continually, it is not sensible to stick to a certain taxonomy which may divert attention from "the real issue which is in fact improving decision making" (Alter 1992).

In this research, we shall focus on developing an information system supporting the daily fleet management tasks in the planning department of a road haulage company. We take as a starting-point the workplace of a dispatcher of the planning department as it exists today. Investigating the daily recurring activities and the problems encountered while performing these activities leads to a design for an information system that supports the dispatcher carrying out his activities.

From our point of view, improving the effectiveness and efficiency of fleet management within the planning department of a road haulage company should be a primary purpose of developing information systems for the road transport business. As a result, the dispatcher within a planning department should not only be supported in performing his genuine trip planning tasks (Type II tasks), but also with his routine administrative tasks (Type I tasks). As we will show in chapter 3, the deficiencies the planning department faces originate to a large extent from difficulties in performing Type I activities.

Recently, *interactive planning systems* (IPS) have been introduced. These systems provide "planning support for planning activities to improve decision making in terms of effectiveness and efficiency" (Anthonisse *et al.* 1988). Thus, interactive planning systems can be viewed as falling into the category of information systems to support decision processes. Examples of recent applications of IPSs can be found in vehicle routing and scheduling (De Jong 1992, Nygard *et al.* 1989, Savelsbergh 1988, Waters 1984) and also in many other areas such as work force planning (Bots 1989, Verbeek 1991), production planning (Verbraeck 1991), and horticulture (Hofstede 1992).

2.4 Information Systems in Road Transport

Information systems for supporting decision processes play an important role in road transport. Application of information systems for road transport has always been of special interest to information systems engineers. This particular interest can be ascribed to (1) the extensive need for information exchange between the parties in the logistics chain, and (2) the complexity of the transport process and the resulting need for adequate planning of transport operations.

We can conclude that, besides the transport of goods, a lot of information is exchanged between the parties in the transport chain. The intensive exchange of information regarding transport operations calls for the development of *interorganizational* *information systems* (IIS). Wierda (1991) defines IIS as follows: "Interorganizational information systems are information systems that are jointly developed, operated, and/or used by two or more organizations that have no joint executive". One of the currently important and actual developments within the field of IIS is the use of *electronic data interchange* (EDI) (Hofman 1989). EDI can be defined as the "paperless, structured, computer-to-computer communication among organizations that have no joint executive" (Streng and Sol 1992). For road haulage companies, the use of EDI can contribute to a more cost-effective operation and improved customer service (Tanja and Smook 1988). Although EDI can be regarded as beneficial for the road transport business, we will not cover this field of interest in this dissertation.

For the past two decades, much attention has been paid to finding a means to solve the vehicle routing and scheduling problem. Most of the efforts in developing DSSs for road transport have originally been made within the Operations Research field. As a result of the efforts that have been put into the development of solutions for vehicle routing and scheduling problems, various algorithms for solving different kinds of vehicle routing and scheduling problems are nowadays available. In fact, these problems are all extensions of the *classic vehicle routing problem* (Bodin *et al.* 1983, p. 80). The various existing vehicle routing and scheduling algorithms differ from the classic one in the way they deal with time-windows, route-length constraints, vehicle/location dependencies, etcetera. A comprehensive survey of these algorithms can be found in Bodin *et al.* (1983).

The first step in developing the existing ISDPs for vehicle routing and scheduling was the implementation of vehicle routing and scheduling algorithms on large computer systems, resulting in *computerized vehicle routing and scheduling systems*. These systems were developed during the late 1970s. The introduction of the microcomputer was the incentive for the introduction of the next generation of systems, the *computer-assisted vehicle routing and scheduling systems*. The main characteristic of this generation is the possibility for the user to tailor the solution to suit his needs. During the mid 1980s, the second generation of computer-assisted vehicle routing and scheduling systems was developed. These systems are capable of handling more types of constraints, and provide a better user interface, especially with respect to incorporating high quality graphics (Bodin 1990, Stefanski *et al.* 1989). Several authors have reported successful implementations of DSSs for vehicle routing and scheduling. An overview of these reports can be found in Sutcliffe and Board (1991).

Although there are a lot of success stories reported in the literature, actual use of ISDPs in road transport is very low. Figures indicate that no more than 5 percent of all haulage companies utilize ISDP for vehicle routing and scheduling (Waters 1990, p. 507). Several reasons exist for this low level of penetration. In general, the road transport business seems to be quit slow in adopting new techniques and systems. There are, however, some "real" difficulties in introducing vehicle routing and scheduling ISDPs in road transport business. Some of the difficulties that should be mentioned in this context are the inadequacy of vehicle routing and scheduling models to represent real situations, the complexity of the computer software, and the excessive amount of input data that is needed to perform useful calculations (Waters 1990). Another important factor, in our opinion, is the presence of *uncertainty* in the information that is needed in vehicle routing and scheduling and the *timely availability* of this information. For example, availability of vehicles can vary due to delays or breakdowns, and orders can be cancelled or "last-minute" orders can arrive (Waters 1989, p. 1101).

The presence of uncertainty is partly caused by the stochastic nature of the transport process. Stochastic fluctuations and unforseen events affect the duration of the trip execution process. Uncertainty in the future demand of transport orders and unforseen changes in the already accepted set of transport orders can also appear.

Coping with stochasticity and uncertainty requires quite a different approach from solving a straight, mathematically formulated vehicle and routing scheduling problem. One possible method for dealing with uncertainty in future demands is the use of a demand-forecasting model, which is capable of anticipating the future incoming flow of demands based on historic data and can therefore be used as a means to support *empty repositioning* of vehicles (Dejax and Crainic 1987, Powell 1988). Dealing with stochasticity in the transport process cannot be fully achieved using historic data. Simulation experiments for detecting time window violations in a retail trade organization, utilizing recorded trip data for building an accurate trip execution model, have shown no improvement in the effectiveness of operational trip planning (De Jong 1992).

In our opinion, using *mobile communications* is a very promising way to deal with the stochastic effects in trip execution. Real-time information about trip execution status can cause uncertainty in the information needed for trip planning to be reduced. Note that mobile communications can also be used for real-time, immediate, repositioning when unexpected transport orders are received or when vehicles are being repositioned for possible demands that never materialize.

2.5 Mobile Communications

Although it may be clear from the previous sections what mobile communications is all about, for the sake of completeness we shall give a definition in the next paragraph.

Mobile communications is a form of communication in which the origin of the message or its destination (or both) can be in motion. Through the use of radio communication techniques the infrastructures for telecommunications and for physical transportation become increasingly spatially separated; the origin and destination of messages no longer coincide with the origin or destination of physical transport (Linnartz 1991, p. 7). For road transport, this means that the driver and the dispatcher are no longer dependent on the fixed telephone service network for making contact with each other.

As we have argued in sections 1.3 and 2.4, we propose the use of mobile communications to deal with the stochastic fluctuations and unforseen events that appear in trip execution, that cause discrepancies between *actual* trip execution status and *perceived* trip execution status. Before turning to the question of how mobile communications can be applied to improve fleet management, we shall give a short overview of the literature in which the potential for mobile communications is indicated. We shall also give a brief introduction to the different kinds of mobile communication systems that exist nowadays.

Several articles in the literature indicate the potential relevance of using mobile communications for supporting fleet management and trip execution processes. Various authors argue that the introduction of mobile communications in road transport can lead to improved quality of information about the trip execution process, an improved performance of drivers and dispatchers, and the ability to assign orders to trucks dynamically (Hallowell *et al.* 1991; Morlok *et al.* 1989; Powell 1990, p. 29; Waters 1990, p. 508). Initial experiments, in which the use of mobile communication systems is restricted to a "communication tool" for dispatcher and driver, i.e., the mobile communication system is used as a replacement for the terrestrial telephone system, point in the same direction (Schrijver 1989). The importance of *automatic vehicle location* (AVL) systems is also recognized (Assad 1988, pp. 34-36).

One of the mobile communication technologies that has been available for a few decades now, is *radio technology*. It has been widely used in public transport, for instance, by taxi cab services, by the emergency services, police, etc. (Hanson 1991). For the majority of road transport businesses, radio-telephones cannot be used for fleet management because the area in which communication with the drivers is possible is too restricted. While the reach of radio systems is very limited, this restriction does not necessarily hold for *paging* systems. Paging systems are available that offer one-way communication over a fairly large area and that can be used for sending small data messages to the receiver (Sharpe 1991). A clear disadvantage of this kind of system is the lack of two-way communication and therefore it is not suited to fleet management applications.

During the last decade, *cellular systems* have become available. These systems consist of a set of "cells," each containing a radio base station interconnected via a landline network (Lee 1989). When a vehicle travels along the cells, communication is initiated with the base station positioned in the current cell. To make contact throughout a wide area, it is necessary to define a fairly large number of cells and consequently install numerous base stations which make the system expensive. Cellular systems currently in use in European countries cannot be used throughout the whole of Europe; these systems, e.g., the Dutch ATF3 system, only operate at a national level. In the near future, however, a pan-European cellular mobile communications systems, called the *Global System for Mobile Communications* (GSM), will become available (Cheeseman 1991). Because of the global character of this system, the GSM system will allow road transport companies to communicate with their drivers throughout a fairly large part of Western Europe. Other cellular systems that have become available recently are *trunking systems* (Britland 1991) and mobile communication systems restricted to exchange of data (Beverwijk 1993). In a trunking system, users share the communication channels and are only allocated a channel when they need to make contact.

One of the recent developments in the field of mobile communications is the introduction of *mobile satellite data communications*. Instead of using base stations located on the ground, communication satellites provide for the connection between the mobile unit and the home base (Singer 1989, pp. 227-233). The main advantage over terrestrial mobile communications systems, as described above, is that the area in which a mobile unit can be reached is much larger. At the moment however, mobile satellite communication systems have several restrictions. For example, the exchange of messages is limited to sending and receiving *data* using a *store-and-forward system* (Vervest 1985). This means that data sent by the originating communicant is stored for a short period of time (in the order of seconds), and then forwarded to the receiving party. A few systems for mobile satellite data communications are in full operational service nowadays. A description of one of these, commercially available, systems can be found in Jacobs *et al.* (1991).

Together with the developments in mobile communications, systems for automatic vehicle location positioning have also matured. The *Global Positioning System* (GPS) offers a world-wide service for determining the position of a mobile unit using several communication satellites. *Loran-C* is a terrestrial system for position reporting of mobile units, originally intended for shipping application, but through expansion of the base station network, the system has been made suitable for land navigation application. The two mentioned systems are capable of determining positions of mobile units with an accuracy of a few hundred meters or less (DGR 1992). In some mobile satellite communication systems, the automatic vehicle location feature is an integrated part of the system.

2.6 Results of Mobile Satellite Communications Trial

To obtain knowledge about the feasibility of supporting fleet management and trip execution utilizing mobile communications, to ascertain the acceptance of drivers and dispatchers with respect to exchanging information using data messages, and to get a global insight into the costs and benefits of mobile satellite data communications, we conducted a trial using a mobile satellite data communication system within several road haulage companies. This trial comprised the feasibility study we proposed to start within our research approach. In this section, we will present, in brief, the results of this experiment. A comprehensive account of this trial is presented in Schrijver (1990).

The experiment with a system for mobile satellite data communications was conducted with four different Dutch hauliers. During a period of six months, including preparations and implementation within the organizations, in total 30 mobile terminals were used for communications between dispatcher and driver. Further, the communication system was equipped with automatic vehicle position reporting facilities. The trucks with the units installed, operated throughout a major part of Western Europe.

Technically, the system functioned without any major disturbances or defects. Acceptance within the planning department and user satisfaction, both for the driver and the dispatcher, proved to be unexpectedly high. Although a negative attitude from the driver might have been expected, because of the encroachment upon the driver's privacy, only about five percent of the drivers who participated in the experiment had negative reactions towards the mobile communication system.

Decreased workload for dispatcher
Saving of time for dispatcher
Less time needed for communications between dispatcher and driver
Saving of time for driver
Increased customer service
Increased loaded ratio
Improved overview of status of trip execution
Increased driver satisfaction
Less telephone costs

Table 2-1 Established major benefits from mobile satellite communications trial

Within the planning department, it appeared to be fairly difficult for the dispatchers to combine their routine job with the actions needed to operate the communication system.

This observation should be regarded as of temporary nature, because during the test period, not all trucks handled by the dispatcher were equipped with the system. Nevertheless, the dispatchers were very enthusiastic about using mobile data communications. A list of major benefits we found during our experiment is given in table 2-1. We emphasize that because of the exploratory nature of the trial, the list of major benefits has a mainly indicative character.

From our experiment with mobile data communications, three important conclusions with respect to future experiments could be drawn (Schrijver 1990, pp. 25-26). One, the experimentation period was too short for the involved hauliers to change their traditional way of planning, only 15 to 20 percent of the total number of trucks within one company were equipped with the communication system. For estimating the effect of the transition to a more dynamic way of planning, an experiment with an entire group of trucks, performing the same operations, and equipped with mobile communications, should be carried out for a longer period. Two, costs and benefits of using a mobile communications system are difficult to determine. Three, within the haulage companies, there exists a need for integrating mobile data communications with other organizational functions, such as order registration and administrative settlement of trips.

The results of this trial exploiting mobile satellite data communications in road transport provide a starting-point for defining further research in supporting fleet management. In the trial we have shown that the use of mobile communications is feasible for road transport and that improved effectiveness and efficiency of fleet management can be expected.

CHAPTER 3

FLEET MANAGEMENT: EXISTING SITUATION

3.1 Introduction

In this chapter, we will present the descriptive conceptual model for fleet management in road transport. We have used the actual descriptions of three major Dutch road haulage companies, which we investigated during our research, to build this model of fleet management.

Earlier in this dissertation, we restricted our research to investigating fleet management in professional road transport. As the road transport business offers a wide range of different types of transport, we restrict our research further to *Full Truck Load* (FTL) transport. In a brief and simplistic way, FTL transport can be described as follows. A customer will call a haulage company with a transport order for a load going from a loading to an unloading location. The haulage company must deadhead a truck from its last unloading location to the new loading location. After the distance between the loading and the unloading location is covered, the truck is unloaded at the unloading location. At that moment in time, the truck must either be assigned a new load, repositioned empty to a location in anticipation of loads to be assigned later, or held at its current location awaiting new transport orders to be placed by customers.

The opposite from FTL transport is *Less Than Truckload* (LTL) transport. In LTL transport, loads occupying only a part of a full truck capacity are combined and moved during the same trip. This process is known as *trip consolidation*. Thus, in one trip, multiple loading and/or unloading locations have to be visited.

The reason for the restriction to fleet management in FTL transport is twofold. One, a major part of professional road transport deals with FTL transport or types of transport that are comparable to FTL transport. Two, FTL transport turns out to be fairly complicated on a daily transport operation basis. Powell (1991, p. 77) states that assigning drivers to loads in FTL transport "although the easiest to state, is the most complicated in actual practice because of the range of issues that must be balanced." He mentions four important issues in assigning drivers to loads:

- *Minimizing total empty distance*. Minimizing the empty distance covered should be interpreted as assigning a driver to the nearest load for which the driver has the correct equipment.

- *Satisfying driver requests*. Balancing driver requests and preferences is important for maintaining overall service quality and driver satisfaction.

- *Satisfying customer needs*. To maintain service quality, it is necessary to cover the load and assign a reliable driver to handle the load.

- *Handling maintenance requests*. Although of less importance, sometimes it is necessary to take into account requests from the maintenance department.

Powell (1990, 1991) distinguishes five major components in sheer FTL operations:

1. *Driver assignment*. Determining what driver should be assigned to each load.

2. *Empty repositioning of drivers*. Determining if and how a driver should be repositioned empty when the driver has finished his or her previous assignment and no new trip has been assigned to the driver.

3. *Load acceptance/rejection*. Determining which loads to accept and which to reject.

4. *On-line pricing*. Determining whether or not to accept a particular price set by a customer or negotiating special prices with a customer on the telephone.

5. *Load solicitation*. Attracting additional freight by calling customers when drivers are still unassigned to a new transport order.

Although we focus on FTL transport in our research, we want to introduce another component to FTL operations, namely *trip consolidation* (Ballou 1992, pp. 506-507; Roy and Crainic 1992). Although Powell (1988, p. 249) explicitly excludes the consolidation function from the FTL operations, we are of opinion that in particular cases trip consolidation can be considered part of FTL operations without detracting from the actual FTL characteristics and without needlessly increasing the complexity of assigning loads to drivers. Including trip consolidation in FTL operations, however, will cause our descriptive conceptual model to be a reflection of a larger part of the road transport business.

Trip consolidation should be viewed as not contrary to FTL transport if three conditions are met: (1) loads to be picked up and loads to be delivered are contained in the trip in sequence, e.g., first all loads are loaded and then all loads are unloaded, (2) trip consolidation takes place before assigning drivers and equipment, and (3) trip planning takes place on a *rolling basis*. It should be emphasized that the consolidation function specified in this way is very restricted compared to the consolidation function that typically arise in the "traditional" vehicle routing and scheduling problem described in chapter 2. Notwithstanding this restriction, incorporating trip consolidation into fleet management of FTL operations makes it possible to provide a more flexible and more accurate description of the fleet management activities in the planning department of professional road haulage companies.

Kamphuis (1984) identifies two additional components in the general transport planning process, which, in our opinion, may be considered as a valuable addition to the five components mentioned by Powell:

1. *Trip preparation.* The preparation of trips includes recording transport orders, filling in trip documents, and preparing driver instructions.

2. *Trip settlement.* Trip settlement comprises gathering the trip documents used during trip execution, invoicing, and generating management information.

As can be concluded from the five components Powell distinguishes in truckload operations, assigning transport orders to the right drivers and equipment is a *driver assignment* problem. The problem to be solved is primarily matching the right driver to the right load in such a way as to minimize total empty miles covered. Nevertheless, other aspects we have mentioned before, such as driver satisfaction and service quality, should also be taken into account.

A graphic depiction of the driver assignment problem is shown in figure 3-1. The current locations of idle drivers are represented by triangles while the loading locations of the trips to be executed are represented by rectangles. The arrows indicate in which direction the loads picked up have to be moved. It should be stressed that figure 3-1 only represents the situation in which several drivers are awaiting a new assignment. In practice it is possible to involve currently active drivers in the assignment process, making use of the estimated completion time of their current assignment.

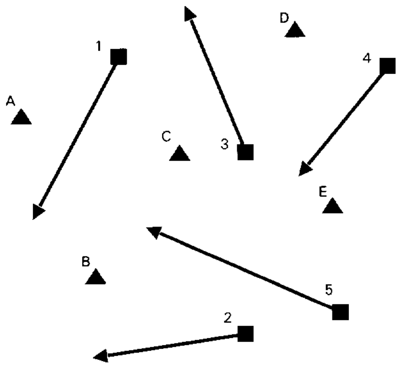

Figure 3-1 Graphic depiction of the driver assignment problem

One of the characteristics of the driver assignment problem is that it is performed on a *rolling basis*. Decisions are made under pressure over the course of the day, while dispatchers constantly have to answer telephone calls from customers placing transport orders or requesting status information, and from drivers checking in to pass on status updates and adjusted estimates of arrival times. In such a dynamic and busy environment, optimization methods for solving the driver assignment problem can not be applied (Savelsbergh 1988). As we have shown in chapter 2, classical algorithms for solving vehicle routing and scheduling problems can not cope with the real-world aspects of particular assignment problems, such as the driver assignment problem.

In European transport, the driver assignment planning problem reduces to a "forward-and-return" planning problem in most cases because of European regulations regarding cabotage and third-country transport. Haulage companies are not allowed to move goods inside a foreign country or between two foreign countries. Therefore, trucks that have travelled to a foreign country are only permitted to accept a follow-on transport order for the country of origin of the truck. (In the near future, the regulations in the European Community will progressively disappear, giving rise to more possibilities for hauliers to pick up and deliver loads, see section 1.2.)

To construct the descriptive conceptual model for fleet management for FTL operations, we have applied the analysis approach proposed by Bots (1989, 1991). The following four steps have been executed:

1. *Problem conceptualization.* Using an object-oriented analysis technique, the relevant objects for fleet management have been identified and a demarcation of the problem area is established. The results of this problem conceptualization are given in section 3.3.

2. *Analysis of fleet management operations.* After having conceptualized the fleet management problem, the tasks carried out by the dispatchers are analyzed in detail. The result of this task analysis is presented in section 3.4.

3. *Trip execution modelling.* Besides a thorough analysis of the tasks carried out by the dispatcher, because of the co-ordination between information system and real system, it is necessary to develop a model of the trip execution process in which the driver is the main actor. The trip execution model is presented in section 3.5.

4. *Problem identification.* After the tasks of the dispatcher have been identified, one should look for the bottlenecks in the execution of these tasks. Once these problems have been found within the problem situation, it should be pinpointed in which task or tasks a specific bottleneck occurs. The result of this problem analysis is given in section 3.6.

We have applied the above-mentioned steps to our problem situation, fleet management of FTL transport. Based on the investigations of three real-life situations, we have developed a descriptive conceptual model for fleet management on an abstraction level where the non-essential details of a specific situation are omitted. Although the conceptual model does not refer to a specific situation, it still represents the essential characteristics of the underlying problem situations. In section 3.2, we will shortly introduce the three haulage companies that constitute the basis for the development of the descriptive conceptual model for fleet management in FTL transport. More detailed descriptions of fleet management processes that have been made using the analysis approach described above, can be found in Babeliowsky (1992), Bernhard (1993), Incontrol (1992) and Schrijver (1991).

3.2 Three Case Studies in Road Transport

In this chapter, a descriptive conceptual model for fleet management operations will be presented. This model should serve as a basis, upon which a solution for the identified problems within the planning department can be developed.

Our descriptive conceptual model is derived from three real-life situations in the Dutch road transport business. During our research, the three cases have proven to be quite representative of Dutch road haulage companies moving full truckloads including the restricted consolidation of trips described on page 31. Our conceptual model of fleet management is based on field research within the planning departments of the three haulage companies we selected for our research. Sitting next to the dispatcher, observing him or her during the execution of the fleet management tasks, asking questions, and feeding back our results and conclusions, resulted in three descriptions of the actual ("as-is") situation. These descriptions contain no normative elements and include specific details of the planning department being described. In constructing the descriptive conceptual model, the specific details were replaced by a more general description of the fleet management process, still referring to the situation as it has been found by the three haulage companies, but omitting the specific properties of the various planning departments.

The next sections will give a short introduction to the general characteristics of the haulage companies investigated in our research.

3.2.1 Case 1: RTT

The first company investigated was a tanker transport company, Rotterdams Tank Transport B.V. (RTT), situated in the port of Rotterdam. This company performs the transport of liquids and granulates, especially hazardous materials, throughout the greater part of Western Europe. The company utilizes different kinds of equipment, such as containers, trailers, and traction units. RTT makes a distinction between *attended* and *unattended* transport for moving goods from a loading to an unloading location. Attended transportation comprises the movement of trailers or containers, put on a chassis, and moved by traction units. As these transports are actually carried out by a driver, this type of transportation is referred to as attended. In contrast, unattended transport includes the transportation of containers by train or ship. Containers are picked up or delivered to a terminal, and the railway-company or the shipping-company is responsible for transport between two terminals.

Most of the operations carried out by RTT can be designated as FTL transport. In some cases, multiple loads are loaded at one loading location for delivery at two or more unloading locations. As tank trailers or containers can have several compartments, it is possible to move more than one load in one trip, although real consolidation of orders is not feasible because of capacity constraints, each container or trailer has a very limited number of compartments, and because of government regulations regarding the transportation of hazardous materials.

RTT forms part of a world-wide transport company that specializes in the transportation of liquid and bulk goods. In Western Europe, there are several other "sibling" companies operating in the road transport market and attempts are made to maximize profitability by co-operation between the various companies. This co-operation is realized by compensating for surpluses or deficits in a company's transport capacity by the temporary exchange of equipment with the other "sibling" haulage companies.

3.2.2 Case 2: Harry Vos

The second road haulage company involved in the development of our descriptive conceptual model, Harry Vos Internationaal Transport B.V., is located in the eastern part of the Netherlands. Harry Vos transports bulk goods using swap bodies. Each lorry and each trailer attached to a lorry can carry a swap body, which can be exchanged with another swap body at almost any location. The use of swap bodies allows for flexibility and efficiency of transportation of cargo. At loading or unloading locations, a loaded or empty swap body can be left behind and can be changed with an empty or a loaded swap body, depending on the type of location. Due to the large number of swap bodies that are being used by Harry Vos, however, the management of equipment becomes very time-consuming and complex.

The type of transport activity at Harry Vos can be called FTL transport. As each swap body is assigned to a specific transport order, and customers in general place transport orders for full truckloads, consolidation of trips is not comprised in the dispatcher's fleet management activities.

Like RTT, Harry Vos has the possibility of exchanging equipment with foreign subsidiaries of the company for a temporary period. Furthermore, if exchange of equipment with the Harry Vos subsidiaries for the smoothing of the surplus or deficit in transport capacity is not feasible, additional equipment can be chartered or additional transport orders can be obtained from fellow haulage companies.

3.2.3 Case 3: Van Amerongen

Our third case-study is a road haulage company situated in the centre of the Netherlands, Van Amerongen Koel- en Vriesvervoer B.V. Van Amerongen distributes cooled and frozen products throughout a minor part of Western Europe, mainly the Netherlands and Germany.

Although at first sight it seems not logical to designate this distribution activity FTL transport, we would like to argue here that the distribution of cooled and frozen cargo at Van Amerongen can indeed be viewed as FTL transport, preceded by some trip consolidation activity.

For several customers, Van Amerongen has taken over the warehousing management function for the cooled and frozen products. This means that the haulage company is responsible for managing the stock of products in several depots throughout the Netherlands. As a consequence, transport orders from customers with managed stock in coldstores, no longer indicate explicitly the loading location as this location depends on the stock level in one of the coldstores. The planning department at Van Amerongen has to look after the stock levels in the different coldstores and replenish the stock if necessary. This is accomplished by moving full truckloads between the coldstores and the factories.

A substantial part of the transports of the cold and frozen products is performed by chartered equipment, placed at Van Amerongen's disposal on a regular basis. One, transport orders are consolidated to trips, using the geographic positions of the unloading locations as the main criterion on which consolidation takes place. Two, the trips as a whole, including the consolidated transport orders, are assigned to the available drivers and equipment. It should be noted that the trips mentioned here do not include moving return freight. Only after a trip departing from the home base or one of the depots has been finished, can a decision be made by the dispatcher on the next assignment to be carried out.

Considering the way of planning and the types of transport activity investigated, we find it legitimate to address the transportation of cooled and frozen cargo at Van Amerongen as a kind of FTL transport for which a driver assignment problem can be formulated, including the limited form of trip consolidation.

3.3 Problem Conceptualization

The previous sections described the three haulage companies involved in the development of the descriptive conceptual model. We made the initial assumption that all three planning departments experienced difficulties carrying out the fleet management activities for reasons indicated in chapter 1. This assumption was supported by preparatory interviews held with management and dispatchers.

An *object-oriented modelling* technique will be used to describe the problem situations and to formulate the actual problems perceived at the planning departments (Coad and Yourdon 1991). *Object classes* and *relationships* between object classes will be specified using this technique. *Object instances* that are part of a problem situation and that are relevant to the problem to be solved, are investigated and corresponding object classes are defined. Attributes and actions of the object classes will also be defined.

The process of specifying object classes and relationships between them will be indicated as *problem conceptualization.* In the course of this process, the following four activities are carried out (Bots 1989, pp. 31-34):

1. *Identification of object classes.* One or more similar objects are perceived as part of the problem situation, and potentially relevant to the problem being analyzed.

2. *Specification of object classes.* The characteristics of the identified objects are expressed in terms of attributes and actions. Object classes with action parts are referred to as *active* object classes. Object classes without an active part are called *passive* object classes (Wierda 1991, p. 116). In the following two sections, the active and passive object class definitions are named and described. In accordance with Bots (1989, p. 32), we will use the following notation style for the definition of object classes:

   object class NAME
   [**attributes**
   First attribute
   |
   Last attribute

   actions
   first action
   |
   last action
   ]

3. *Relating an object class to other object classes.* Indicate for each object class which of its actions affect other object classes, e.g., by changing their attribute values or by triggering some of their actions.

4. *Demarcation of problem boundaries.* Determine which object classes, attributes, and/or actions are really relevant to the problem situation at hand. Section 3.3.3 will provide a demarcation of the problem situation for fleet management and will depict the fleet management conceptual model in a graphic way.

3.3.1 Active Objects

In fleet management, several active objects can be identified. In this section we will specify the active object classes that are relevant to the fleet management process. This implies that an active object class in the conceptual model for fleet management has actions that in one way or another affects the execution of tasks in the fleet management process. If an object has actions, however, that are not relevant to the conceptualization of the fleet management process, these actions will not be included in the action part of the object class specification. If all actions of a certain object are to be excluded from the action part because of this reason, the object will be regarded as a passive object.

In the planning department, several types of information workers play a part in the fleet management process. Firstly, the DISPATCHER performs the actual planning tasks and takes care of the communication with the customers. Furthermore, he or she is responsible for the acquisition of transport orders.

object class DISPATCHER
[**attributes**

Assigned equipment	A list of equipment the dispatcher is responsible for
Assigned region	A list of regions the dispatcher is responsible for
Assigned customers	A list of customers the dispatcher is responsible for

actions
assign transport orders to trips
arrange transport combinations
assign trips to transport combinations
acquire transport orders
eliminate surplus or deficit of equipment
eliminate surplus or deficit of transport orders
handle contact with customer
]

Secondly, the dispatcher is assisted by an ASSISTANT DISPATCHER. The assistant dispatcher registers the transport order data and the data that become available during trip execution, he or she also handles the contacts with the drivers.

object class ASSISTANT DISPATCHER
[**attributes**

Assigned equipment	A list of equipment the assistant dispatcher is responsible for
Assigned region	A list of regions the assistant dispatcher is responsible for

actions
register transport order data
register trip execution data
handle communication with driver
]

Lastly, an ADMINISTRATIVE ASSISTANT is present in the planning department. His or her main task is to prepare drivers instructions and legal documents, such as waybills. The final settlement of transport dossiers to enable invoicing of the transport order also forms part of his or her activities.

object class ADMINISTRATIVE ASSISTANT
[**attributes**

Assigned equipment	A list of equipment the administrative assistant is responsible for
Assigned region	A list of regions the administrative assistant is responsible for

actions
prepare driver instructions
prepare legal documents
prepare invoicing
file transport dossiers
]

Although we have presented the clusters of actions carried out by the dispatcher, the assistant dispatcher, and the administrative assistant as strictly separated from each other, it is common practice in the road haulage business for the dispatchers to take over another dispatcher's activities if necessary. In the case of absence of one of the dispatchers or owing to pressure of work, taking over equal or less responsible activities from fellow dispatchers may be necessary to guarantee continuity of the fleet management process.

The DRIVER plays an important role in performing trip execution activities. Based on the instructions the driver receives from the planning department, several activities are carried out in accordance with the trip plan. These activities include driving to a loading location, loading, driving to an unloading location, unloading, resting, etc. A complete model of the trip execution process as it takes place in the context of fleet management will be presented in section 3.5.

object class DRIVER
[**attributes**

Name	Name of driver
Availability	To indicate when driver will be on duty
Skills	To indicate certain skills driver may have
Preferences	To indicate some preferences driver may have regarding carrying out transport orders

actions
be absent or present
signal preferences
]

Actual transport is carried out using different kinds of equipment. To enable flexibility of transport, to offer specialized transport services, and to allow for multi-modal transport of goods along the logistics chain, road haulage companies utilize diverse types of equipment.

First of all, a vehicle should be available that is capable of transporting goods over a road network or moving around other equipment. Therefore, this vehicle should be able to move itself and will be driven by a driver. In our conceptual model of fleet management this type of equipment will be called a *truck*. A TRUCK can be a lorry or a traction unit, respectively having any capacity to move goods or not.

object class TRUCK
[**attributes**

Id number	Company's internal identification number
License number	License number of truck
Truck type	Indicates whether truck is a traction unit or a lorry
Availability	Indicates when truck will be available
Capacity	On-board capacity, if any
Characteristics	Special characteristics of truck
Status	Current status of truck
Location	Current location of truck

actions
be (un)available
]

The object class TRAILER is comprised of different kinds of trailers. A *semi-trailer* can be attached to a lorry to increase transport capacity. In the case of the truck being a traction unit, attaching a *trailer* is essential to actually perform transport activities. In most cases, a trailer will have transport capacity, although this is not necessarily the case. A trailer may just be a chassis on which transport units can be placed. As these transport units are interchangeable, we will refer to them as INTERCHANGEABLE TRANSPORT UNITS. Examples of interchangeable transport units are containers and swap bodies. It should be noted that interchangeable transport units can in some cases also be put on the traction unit.

object class TRAILER
[**attributes**

Id number	Company's internal identification number
License number	License number of trailer
Trailer type	Indicates type of trailer
Availability	Indicates when trailer will be available
Capacity	On-board capacity, if any
Characteristics	Special characteristics of trailer
Status	Current status of trailer
Location	Current location of trailer

actions
be (un)available
]

object class INTERCHANGEABLE TRANSPORT UNIT
[**attributes**

Id number	Company's internal identification number
Unit type	Indicates whether unit is a container or a swap body
Availability	Indicates when unit will be available
Capacity	Capacity of unit
Characteristics	Special characteristics of unit
Status	Current status of unit
Location	Current location of unit

actions
be (un)available
]

To execute a series of transport orders, the dispatcher must determine which equipment and which driver to assign to the transport orders, giving rise to a combination including driver, truck, and, if required, trailer plus the interchangeable transport units used for the trip.

object class TRANSPORT COMBINATION
[**attributes**

Driver	Driver of the truck
Truck	Truck used for carrying out the trip
Trailer	Trailer attached to the truck, may be absent
Transport units	Interchangeable transport units that form part of the combination, may be absent

actions
report problems encountered
report trip status updates
report trip execution data
]

The customer is important in the fleet management model. After having accepted the transport charge for carrying out a certain transport, a CUSTOMER can place a transport order requesting the transportation of goods from a certain origin to a certain destination at a certain date and time. After the order has been placed, changes may occur in the transport order or the order can even be cancelled by the customer. Furthermore, it is important for the customer to be informed about the execution status of the transport order and therefore inquiries will be made at the planning department.

object class CUSTOMER
[**attributes**

Name	Name of customer
Address	Address of customer
Telephone number	Telephone number at which customer can be reached
Contact person	Person to get in touch with if problems or questions arise
Specific demands	Special requirements for carrying out transport orders in general from customer

actions
place transport order
change transport order
cancel transport order
request information
]

A transport order is carried out from an origin to a destination. We will refer to these origins and destination as *locations*. A LOCATION is a place where cargo can be loaded or unloaded during a certain *time window*. The time window defines the interval during which the location will be opened for loading or unloading of cargo. As a location can refuse to load or unload cargo for various reasons, this object class should be regarded as active.

object class LOCATION
[**attributes**

Name	Name of location
Address	Address of location
Time window	Defines the customary time constraints for loading or unloading
Type of location	Indicates whether the location is a loading or unloading location
Specific demands	Special requirements for loading or unloading determined in general by the location
Specific route instructions	Special instructions regarding route to a location and at the location itself

actions
refuse loading or unloading of cargo
]

To smooth out temporary fluctuations in the amount of transport orders to be carried out, additional equipment can be chartered from other haulage companies on a temporary basis or transport orders can be forwarded to other haulage companies. A haulage company co-operating with the planning department in this manner will be called a CO-OPERATING HAULAGE COMPANY.

object class CO-OPERATING HAULAGE COMPANY
[**attributes**

Name	Name of co-operating haulage company
Address	Address of co-operating haulage company
Telephone number	Telephone number of co-operating haulage company

actions
eliminate surplus or deficit of equipment
eliminate surplus or deficit of transport orders
]

The government is indirectly involved in the fleet management process as it enforces regulations on some aspects of the trip execution process. Examples of these regulations are driving time regulations for the driver, restrictions regarding the transportation of goods in or between foreign countries, and regulations regarding hazardous materials transport, etc.

object class GOVERNMENT
[**actions**
enforce regulations
]

3.3.2 Passive Objects

In this section, we will specify the object classes of objects that are unable to carry out certain actions that are relevant to the fleet management process.

object class TRANSPORT ORDER
[**attributes**

Customer	Customer placing the transport order
Shipper	Party actually sending the cargo
Consignee	Party cargo is consigned to
Cargo to be shipped	Description of cargo to be transported
Quantity to be shipped	Quantity of cargo to be transported
Reference number	Customer's internal reference number for order
Loading location	Location order should be loaded at
Requested loading time	A specific loading date and time can be requested
Unloading location	Location order should be unloaded at
Requested unloading time	A specific unloading date and time can be requested
Terms of delivery	Conditions for carrying out order

]

As expressed earlier in this object specification, customers can place transport orders at the planning department of the road haulage company, which triggers the actual dispatching process. In a TRANSPORT ORDER the type and amount of cargo are defined, as well as the times and locations of loading and unloading. Furthermore, some additional information, such as the shipper, the consignee, a reference number, and the terms of delivery can be specified.

The primary task of the dispatcher is to determine a number of transport orders to be carried out within a certain period and assign equipment and drivers to execution these transport orders. The result of performing this *trip planning* task is a TRIP PLAN specifying which trips should be executed within a certain period, and which drivers and equipment are assigned to these trips.

object class TRIP PLAN
[**attributes**

Start date	Start date for execution of trip plan
End date	End date for execution of trip plan
Status	Current status of trip plan
Trips	Trips belonging to trip plan
Feasibility	Indicates feasibility of trip plan

]

A trip plan consists of different trips. A TRIP consists of the planned execution of one or more transport orders. Data regarding the loading and unloading process, recorded during trip execution, are registered. As a trip models actual transportation from a loading to an unloading location, information regarding actual trip execution is included in the object class specification of a trip.

object class TRIP
[**attributes**

Transport orders	Order(s) to be executed within trip
Assigned combination	Combination that is assigned to trip
Status	Current status of trip
Delay	An indication whether or not delay has occurred during trip execution
Planned loading	Loading dates and times as indicated in trip plan
Estimated loading	Estimated dates and times of loading, updated during trip execution
Actual loading	Actual loading dates and times as recorded during trip execution
Duration of loading	Indicates actual duration of loading process
Estimated unloading	Estimated dates and times of loading, updated during trip execution
Actual unloading	Actual unloading dates and times as recorded during trip execution
Duration of unloading	Indicates actual duration of unloading process
Quantities loaded	Actual quantities of cargo loaded as recorded during trip execution
Remarks	Any special comments

]

After having defined a trip plan for a certain period, the driver should be informed about the trip(s) he or she has been assigned to. Therefore, the driver receives a DRIVER INSTRUCTION in which the necessary information concerning the trip to be executed is formatted in a way easily understood by the driver. In some cases, some additional instructions will be contained in the driver instruction.

object class DRIVER INSTRUCTION
[**attributes**

Trip	Trip driver instruction relates to
Combination	Transport combination arranged for carrying out trip
Planned actions	Actions driver should carry out
Legal documents	Legal documents, such as waybills and permits driver needs for carrying out transport orders
Special directions	Special instructions to be followed by driver

]

After completion of the trip, a TRANSPORT DOSSIER is filed. The transport dossier contains information about the transport order and actual trip execution data. Further, it contains the documents that were used during the execution of the transport order, such as the original order confirmation from the customer and the filled waybills that belong to the transport order.

object class TRANSPORT DOSSIER
[**attributes**

Transport order	Order for which dossier is filed
Trip execution data	Information about actual execution of the order
Waybills	Filled waybill(s) that relate to the order
Remarks	Any special remarks, e.g., occurrence of excess costs, etc.

]

As soon as the transport dossier is closed, an INVOICE will be prepared and sent to the customer. Possible excess transport costs, such as exceeded waiting times at a loading or unloading location, for which the customer may be held responsible, will be charged in addition.

object class INVOICE
[**attributes**

Transport order	The transport order that is to be invoiced
Trip	The trip in which the order has been carried out
Amount of cargo loaded	Actual amount of cargo transported
Excess costs	Excess transport costs to be charged to the customer

]

3.3.3 Demarcation of Fleet Management

In the previous two sections we have identified and specified the object classes we consider relevant to the fleet management process. The next step in defining a conceptual model of fleet management is to determine the boundaries of the problem situation. Bots (1989, p. 97) proposes the information paradigm as a tool for outlining the information system (IS), the real system (RS), and the environment of the RS/IS-combination. In section 1.3 of this dissertation, we presented an RS/IS-combination, modelling fleet management as the IS-component and trip execution as the RS-component controlled by the fleet management process.

Since we wish to provide support for the fleet management tasks, it seems logical to consider the dispatcher(s) as the IS-component. The "demarcation rule" will assist us further in defining the RS-component and the environment of the RS/IS-combination (Bots 1989, p. 10). The dispatcher has no direct control over the attributes of the customers, locations, co-operating haulage companies, and the government. Therefore, we consider instances of these object classes to belong to the RS/IS-combination's environment, rather than being part of the RS.

From the specification of attributes of the object classes for the driver and the equipment used for trip execution, i.e., the truck, the trailer, and the interchangeable transport unit, we conclude that the dispatcher has no control over these object classes. He or she has no ability to change the attribute values of instances of one of the equipment or driver object classes. This therefore qualifies trucks, trailers, interchangeable transport units, and drivers as part also of the environment. Although this seems to be contradictory to the fact that a dispatcher has to exert control over the rolling-stock and the drivers to optimize profitability and customer service, one should realize that the dispatcher has control over the arrangement of the transport combinations, and thus has control over all the attributes of a transport combination. Consequently, a transport combination forms part of the RS-component.

The object classes for transport orders, driver instructions, transport dossiers, invoices, trip plans, and trips belong to the IS-component of our system. These object classes have been introduced into our conceptual model to store and retrieve information used in the IS-component.

Our conceptual model for fleet management consists of all the object classes we have defined, the demarcation of the IS and RS components, and the environment. A graphic representation of the fleet management conceptual model is shown in figure 3-2. Object classes are represented by an *icon*, accompanied by the name of the object class. An icon is a schematic, unique, representation of the object class. Actions are represented by arrows, from the acting object class pointing to the object classes influenced by the action. A dashed arrow indicates that the corresponding action induces the influenced object to perform an action of its own, rather than modifying some of its attributes directly.

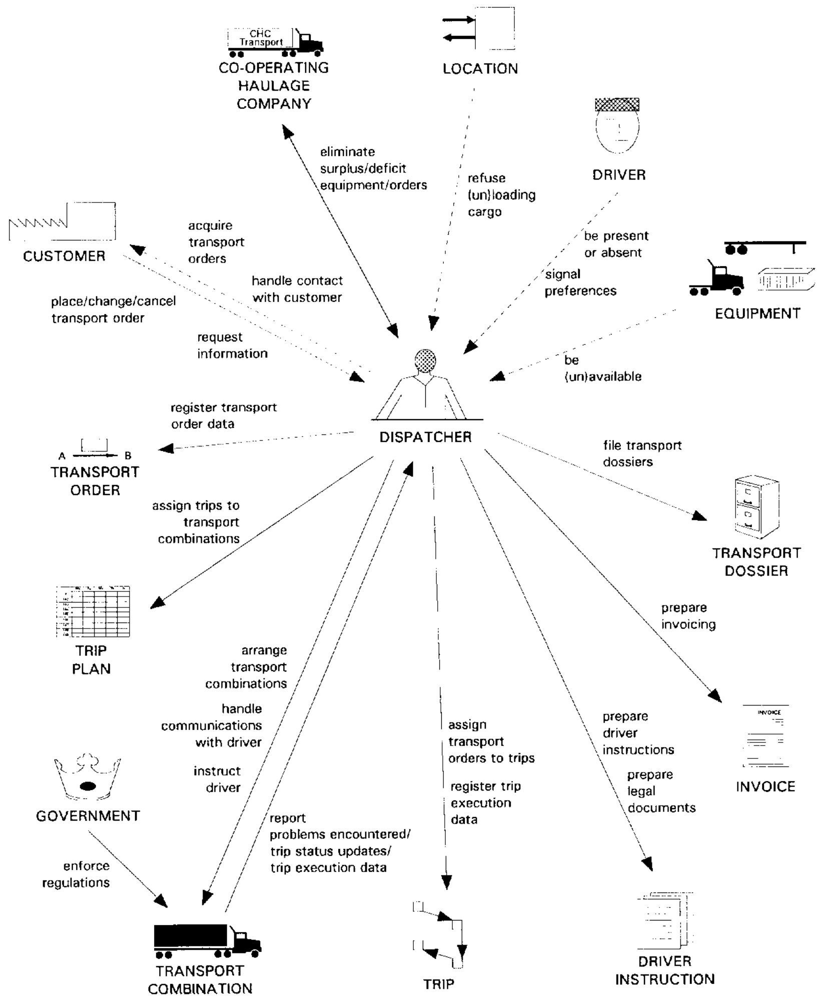

Figure 3-2 Graphic representation of the fleet management conceptual model

3.4 Task Analysis

Further analysis of the dispatcher's activities with respect to their fleet management activities has been carried out using the *task analysis* technique, developed by Bots (1989). This technique is based on the assumption that every information worker in an organization performs *tasks* and takes *decisions*. When drawing the structure of the decision process, hereafter called the *task structure*, tasks are represented by rectangles with the name of the task in the rectangle. Decisions are depicted by circles with the name of the decision to the right of the circle. The order in which the tasks and decisions are carried out, is determined by arrows. Arrows departing from a decision have a proposition associated with it. The arrow that departs from a decision will only be followed if, and only if, the associated proposition is met.

Task structures can be recursive: this means that a task itself can be a task structure. In a task structure, this is depicted by a little "bomb" in the upper left corner of the rectangle. Using the recursiveness property of task structures, a task can be specified on several abstraction levels until a certain level of detail is reached.

Within task structures, it is possible to model a co-ordinating mechanism. A decision can be put on the "agenda," causing another task structure to be executed. Decisions used to model this co-ordinating mechanism are called *signals*. A signal is represented by a dotted circle. Figure 3-3 presents an overview of the task analysis primitives.

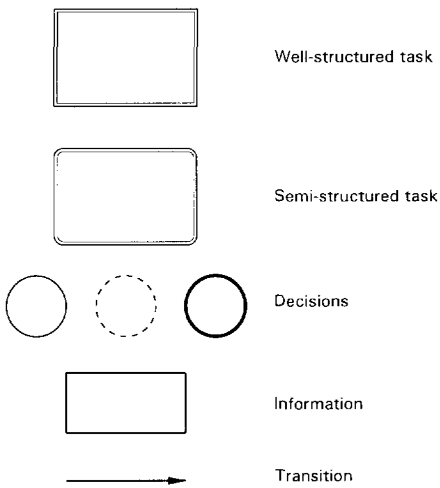

Figure 3-3 Overview of symbols used in task analysis

In our descriptive conceptual model of fleet management, the following five tasks have been found to make up the overall fleet management task.

1. HANDLE TRANSPORT ORDER REQUEST. Receive and treat transport order request and decide whether or not to accept transport order.

2. PLAN TRANSPORT ORDERS. Plan and consolidate transport orders thus preparing a trip plan.

3. INSTRUCT DRIVER. Prepare driver instructions and communicate instructions to drivers.

4. MONITOR TRIP EXECUTION. Receive information or requests from customers, drivers, and co-operating haulage company during the trip execution process, and take appropriate action.

5. SETTLE TRIPS. Settle trips administratively and prepare invoicing.

Figure 3-4 presents the task structure for the main fleet management task.

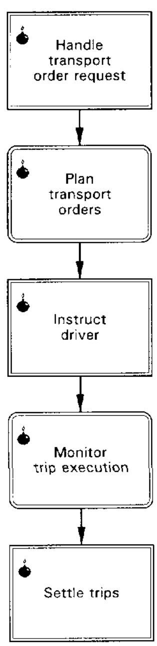

Figure 3-4 Task FLEET MANAGEMENT

The fleet management operations in professional FTL road transport are order-driven. In fact, incoming transport orders form a trigger for executing fleet management tasks. Requests for the execution of transport orders come in at the planning department where the dispatcher has to decide whether a transport order requested by a customer can be accepted by the road haulage company. This decision is made on two main criteria: availability of equipment and drivers, and economic justification. If it is already known at the moment an order arrives that there is not sufficient equipment available for executing the transport order at the requested time, the dispatcher will assess the possibility of arranging additional capacity. If arranging additional capacity is unlikely, the transport order is rejected. If an accepted transport order is a "last-minute" request for the movement of goods, the order is included in the trip plan and an adjustment to the trip plan is made.

The task HANDLE TRANSPORT ORDER REQUEST comprises the FTL operation components "Load acceptance/rejection" and "On-line pricing," mentioned by Powell, which have been described in section 3.1. Figure 3-5 shows the task structure for handling transport requests. The task ADJUST TRIP PLAN will be explained later in this section.

After a transport order has been accepted for execution, a trip plan is prepared in which equipments and drivers are assigned and the actual trip *plan*, i.e., the starting and finishing times of a trip, are determined. Before starting the actual trip preparation task, the availability of drivers and equipment for a certain period of time should be determined. Due to absence or maintenance, availability of drivers and equipment will vary, having established the availability of drivers and equipment, transport combinations can be arranged.

Meanwhile, if the type of transportation requires trip consolidation, transport orders are clustered into trips to be assigned as a whole to a transport combination. We emphasize that this task can be omitted from the task structure when straight FTL transport is involved.

Assigning transport combinations to trips can be regarded as a two-stage process. Firstly, a provisional trip plan is prepared, which is based mainly on the transport order data, transport combination availability, and road network information. The primary purpose of putting together this provisional trip plan for the dispatcher is to gain insight into the feasibility of the current trip plan, thereby obtaining an indication of a surplus or a deficit of orders or equipment in the trip plan.

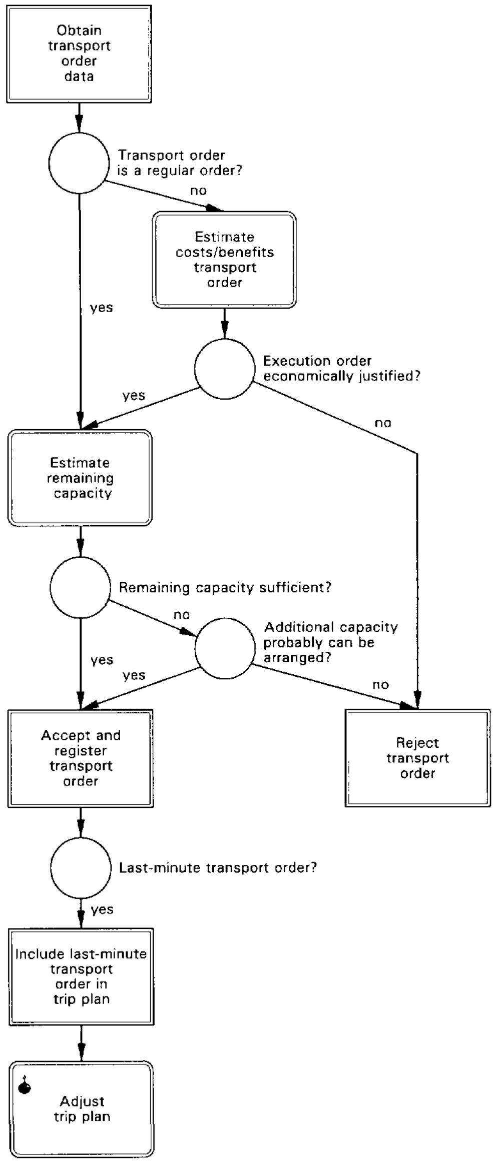

Figure 3-5 Task HANDLE TRANSPORT ORDER REQUEST

The second task comprises the preparation of the final trip plan, in putting together this trip plan, information on the actual status of the trip execution is taken into account. To accomplish this, important changes in the trip execution status cause the task

ADJUST TRIP PLAN to be executed. (The task structure for adjusting the trip plan will be discussed later on in this section.) An assignment in the current trip plan for a certain transport combination remains labelled provisional in a virtual sense as long as the transport combination has not started the next assignment, as the dispatcher still has the opportunity to adjust the assignment.

The task structure for the task PLAN TRANSPORT ORDERS is given by figure 3-6. This task includes the components "Driver assignment" and "Empty repositioning of drivers" from the FTL framework presented earlier in this chapter. Empty repositioning of transport combinations has not been made explicit, but is incorporated in the trip planning tasks.

See figure 3-7 and figure 3-8 for the task structures for arranging the transport combinations and preparing the provisional trip plan.

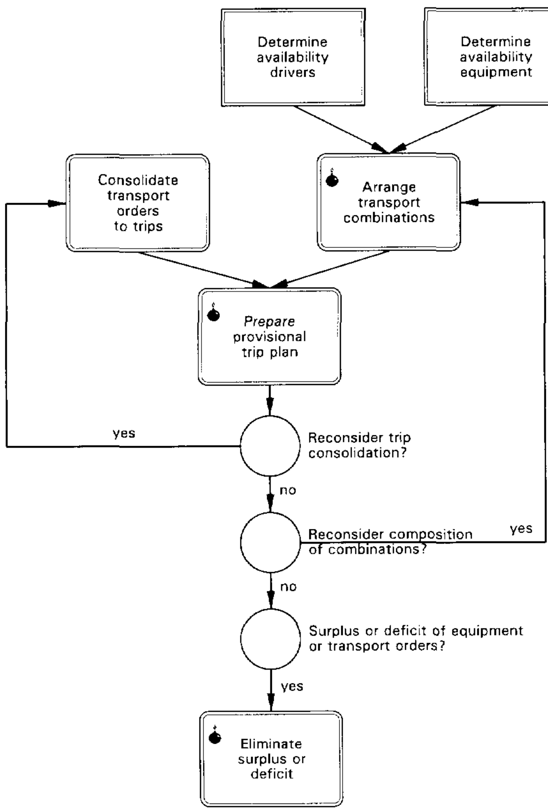

Figure 3-6 Task PLAN TRANSPORT ORDERS

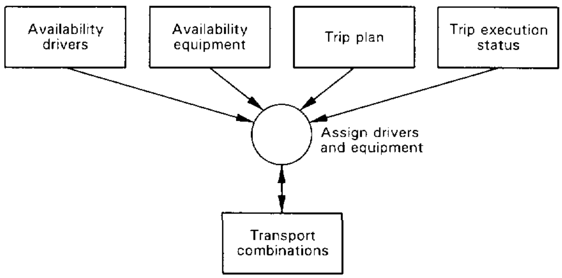

Figure 3-7 Task ARRANGE TRANSPORT COMBINATIONS

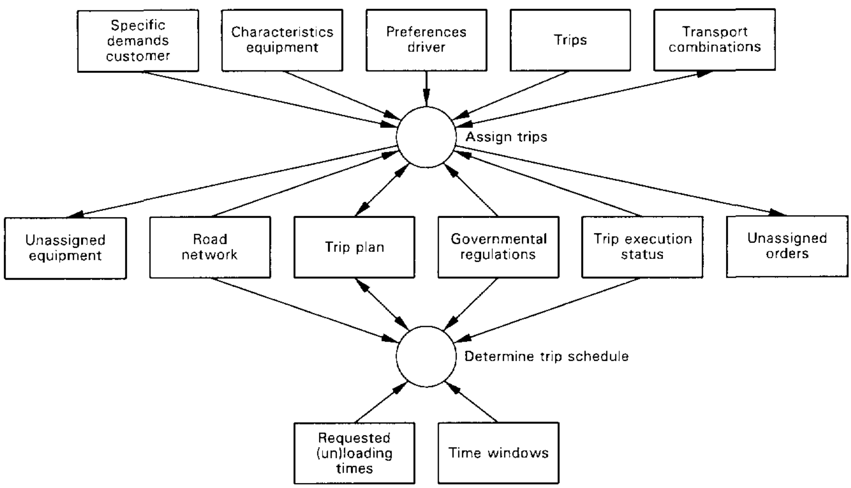

Figure 3-8 Task PREPARE PROVISIONAL TRIP PLAN

As professional road transport is dependent on the incoming flow of transport orders which has a stochastic character, the number of transport orders to be executed will vary over time. Even more important, the number of transport orders can not be predicted for a certain period of time in the (near) future. Thus, not only the incoming flow of orders has a stochastic character, but also the trip execution process is influenced by stochasticity. In general, driving, loading, and unloading times can not be determined exactly beforehand. As a consequence, real trip duration will differ from the expected trip duration in most cases, which will result in a difference between real and expected driver and equipment utilization.

The combined effects of the stochasticity in the incoming order flow and the stochasticity in the trip execution process can cause a surplus or a deficit in the drivers and equipment current availability. The dispatcher can apply four strategies to eliminate this surplus or deficit, depending on the type of capacity problem: (1) acquire additional transport orders from a customer or a co-operating haulage company, (2) forward transport orders to a co-operating haulage company, (3) charter additional equipment and/or drivers, or (4) hire out superfluous equipment and/or drivers.

The task structure for the task ELIMINATE SURPLUS OR DEFICIT is shown by figure 3-9.

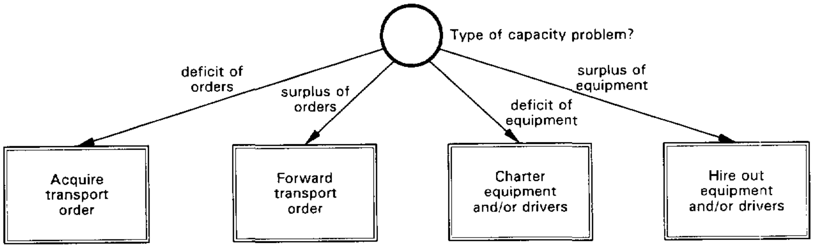

Figure 3-9 Task ELIMINATE SURPLUS OR DEFICIT

The third task in the overall fleet management task comprises instructing the driver about the next assignment to be carried out. Using an overview of the trip plan for the next planning period, which is also used for providing trip plan information to other departments in the road haulage company, instructions are given to the driver either by providing trip information over the telephone or by handing the driver written instructions. The latter alternative is preferred over the former because the chances of misunderstandings between dispatcher and driver diminish. If the driver is able to return to the home base to pick up his or her instructions, legal documents needed for trip execution, such as waybills, will also be prepared for the driver. The task INSTRUCT DRIVER is represented in figure 3-10.

Having instructed the driver, the dispatcher must monitor the execution of the trips. During trip execution, the telephone is used by the drivers to inform the dispatcher about trip status changes and the progress of planned trip activities, besides telephone calls from the drivers, the dispatcher also receives calls from customers and co-operating haulage companies. As the dispatcher is unable to determine in advance who is the originator of the calls he or she is answering, and telephone calls from customers or other haulage companies in most cases involve questions concerning trip execution monitoring, we classify the handling of all telephone calls as part of the task MONITOR TRIP EXECUTION. See figure 3-11 for a task structure of this task.

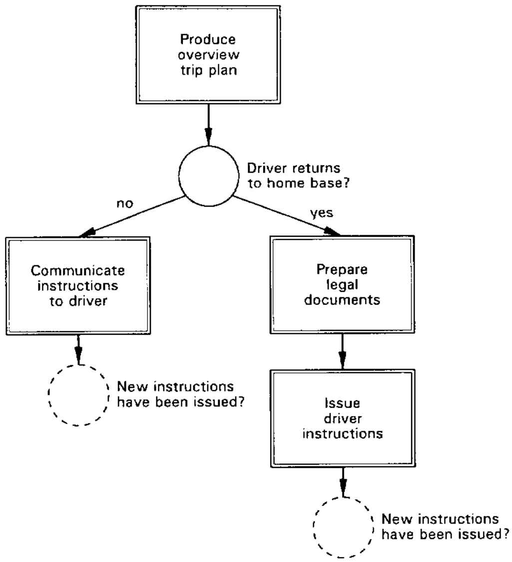

Figure 3-10 Task INSTRUCT DRIVER

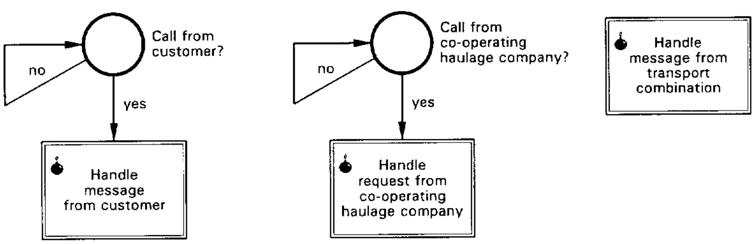

Figure 3-11 Task MONITOR TRIP EXECUTION

The task HANDLE MESSAGE FROM CUSTOMER deals with acknowledging three types of messages: (1) a change in transport order data, (2) cancellation of a transport order, or (3) a request for information concerning the trip execution status of a specific trip. When the message from the customer involves a change in a transport order or the cancellation of a transport order, alterations must be made to the trip plan, and if the alterations apply to a transport order already included in a trip plan or if changes in an as yet, unassigned transport order affect the current trip plan, adjustments will need to be made to the trip plan. The request for trip status information can be answered immediately if the requested information is available. If this is not the case, other dispatchers will be consulted, and if they are not able to give a decisive answer to the question, the driver responsible for the execution of the transport order in question must be contacted.

The task structure for handling messages from the customer is given in figure 3-12.

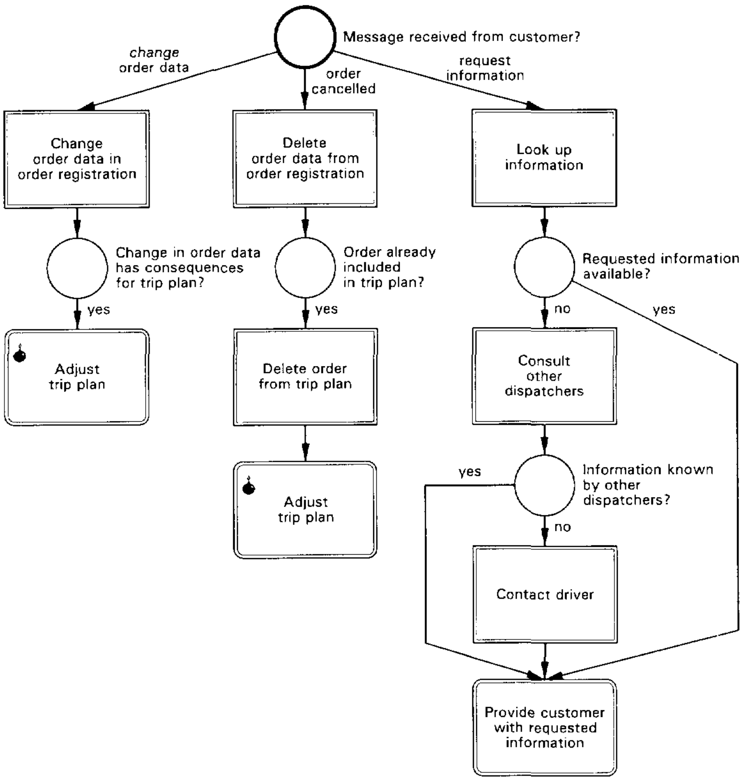

Figure 3-12 Task HANDLE MESSAGE FROM CUSTOMER

The task HANDLE MESSAGE FROM TRANSPORT COMBINATION resulted from a need to describe the way dispatchers deal with messages from transport combinations (figure 3-13). Drivers will contact the planning department to pass on messages concerning the following events:

- A significant delay has occurred;
- A delay has occurred during loading or unloading;
- A general problem has occurred;
- A location refuses to load or unload cargo;
- Loading or unloading of cargo is finished;

- An assignment is finished.

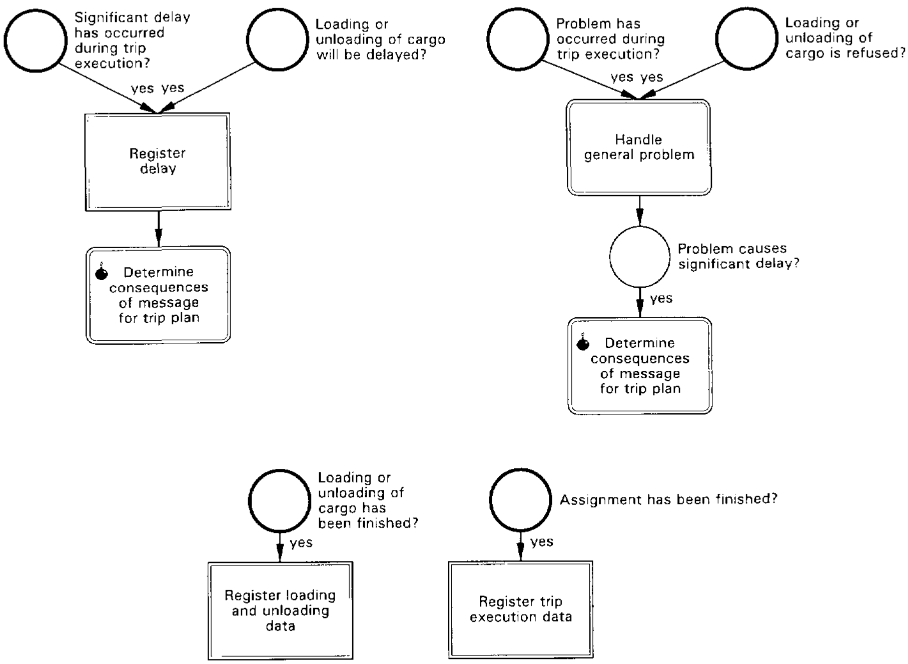

Figure 3-13 Task HANDLE MESSAGE FROM TRANSPORT COMBINATION

In the case of delays, an estimate of the deviation between trip plan and trip execution needs to be made, upon which a decision can be taken whether or not to inform the customer about the delay and make adjustments to the trip plan. In the case of problems, as well an estimation of the deviation that possibly will result from the problem has to be made as the problem itself has to be solved, either by the dispatcher or by the driver. If problems have occurred, customers have to be informed about the consequences of the problems as this is part of providing customer service. If a problem or a delay occurs that the customer can be held responsible for, pressure can be exerted on the customer to minimize the consequences of the problem. Making an estimation, informing a customer, and adjusting the trip plan is included in the task DETERMINE CONSEQUENCES OF MESSAGE FOR TRIP PLAN, see figure 3-14.

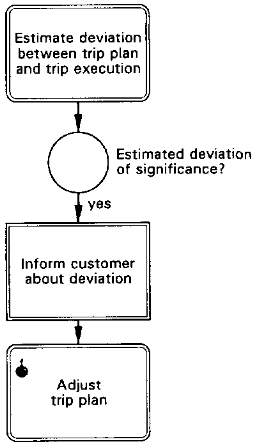

Figure 3-14 Task DETERMINE CONSEQUENCES OF MESSAGE FOR TRIP PLAN

It is mentioned several times in the discussion of the tasks executed by the dispatcher, that a trip plan can be or must be *adjusted*. In the two-stage trip planning process we discussed earlier (see page 50), adjusting the trip plan constitutes the second stage.

The task ADJUST TRIP PLAN starts with identifying the *inappropriate* trip assignments. We call a trip assignment inappropriate when the current trip assignment of a transport combination no longer matches the next trip assignment to be executed by this transport combination. In this context, two trip assignments do not match each other when the (expected) end time of the first is in conflict with the (planned) start time of the second. The existence of a conflict can be explained in two ways. One, starting from the assumption that the expected end time of the first assignment will be correct, the second trip assignment can not be started on time, i.e., the two trip assignments are in conflict in a rational sense. Two, if the first assignment is to be expected finished too soon compared to the planned starting time of the second assignment, i.e., the two trip assignments conflict in an economic sense. Determining whether or not an assignment ends too soon requires the application of some kind of norm that can be economically interpreted, e.g., a norm can be set for a waiting time of two hours for a driver.

Having identified the inappropriate trip assignments, trip plan feasibility can be enhanced by *exchanging* inappropriate trip assignments. In this exchange process, unassigned transport orders and unassigned equipment can also be involved. This exchanging process is repeated until a feasible trip plan is obtained. If the resulting trip plan yields a surplus or deficit of orders or equipment, this surplus or deficit should be eliminated, if possible.

See figure 3-15 through figure 3-17 for the task structures regarding the adjustment of the trip plan.

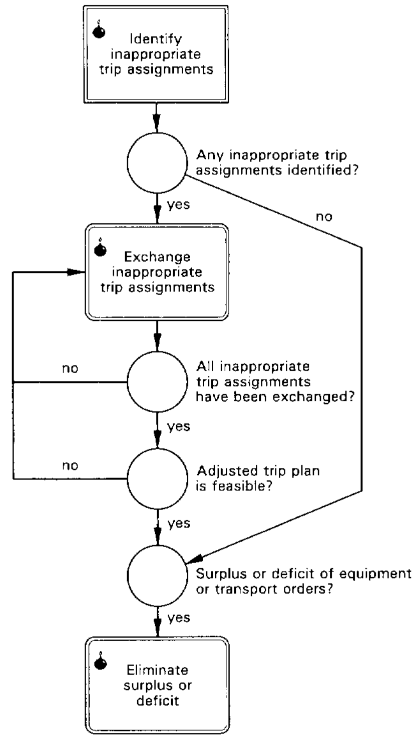

Figure 3-15 Task ADJUST TRIP PLAN

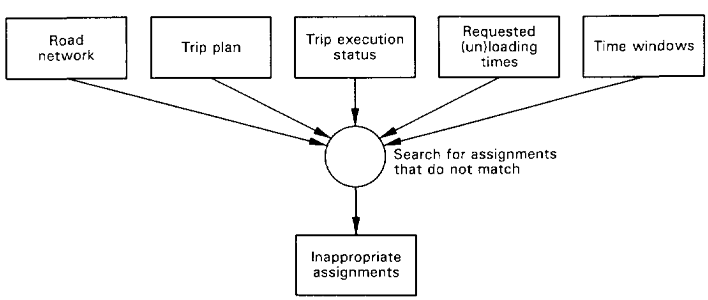

Figure 3-16 Task IDENTIFY INAPPROPRIATE TRIP ASSIGNMENTS

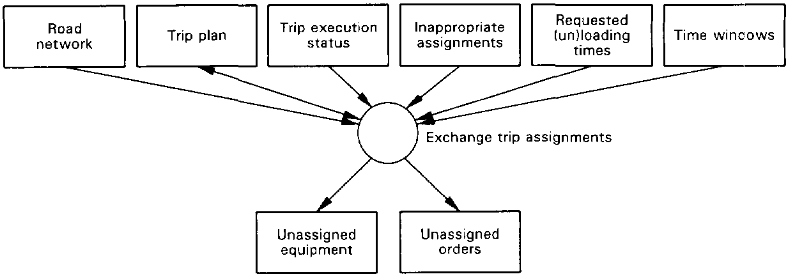

Figure 3-17 Task EXCHANGE INAPPROPRIATE TRIP ASSIGNMENTS

In analogy to the way the dispatcher handles a surplus or deficit in transport orders or equipment, a co-operating haulage company also tries to eliminate surpluses and deficits. For this purpose, during trip execution monitoring the dispatcher receives messages from the co-operating haulage companies concerning requests for forwarding transport orders or hiring equipment. If a surplus of transport orders or equipment exists in the present, transport orders will be forwarded or equipment will be hired out, respectively. If a deficit of transport orders or equipment exists, transport orders are acquired or equipment will be chartered. For a task structure of the task HANDLE REQUEST FROM CO-OPERATING HAULAGE COMPANY, see figure 3-18.

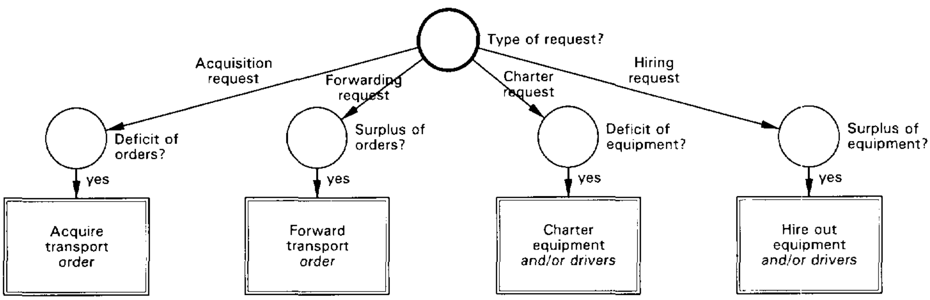

Figure 3-18 Task HANDLE REQUEST FROM CO-OPERATING HAULAGE COMPANY

The last task in the overall fleet management process is the settlement of trips. Once all trip execution data have been collected, transport dossiers can be completed and invoices made out and sent off. If information regarding the trip execution is found to be missing, the missing information must be gathered before completing the transport dossier in question. This can be achieved by scanning the filled documents or by asking the dispatcher the trip was assigned to. If, during the completion of transport dossiers, excess transport costs are encountered, these costs are signalled and treated separately.

Lastly, preparations are made to enable the invoicing of the completed trips. A task structure for the task SETTLE TRIPS is shown by figure 3-19.

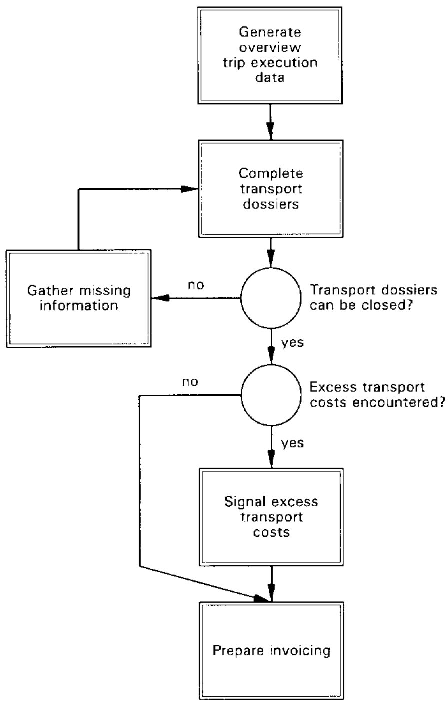

Figure 3-19 Task SETTLE TRIPS

3.5 Modelling Trip Execution

The previous section specifies a model for the dispatcher's activities in the field of fleet management using the task analysis technique. As can be concluded from the resulting task structures, *co-ordination* between the tasks carried out by the dispatcher and the trip execution process plays an important part in the fleet management process. Continuous updates of trip execution status are necessary to adjust the trip plan adequately and to inform the customer in a proper way about trip progress. These updates are used to control the trip execution process to assign trips to transport combinations at as low as possible cost, whilst still satisfying the demands of drivers and customers. Eventually, controlling the trip execution process in an adequate sense will improve the overall performance of the planning department.

Co-ordination between the tasks of the dispatcher and the driver is a requirement to be able to accomplish transport activities. According to Mintzberg (1983, pp. 4-7), several co-ordinating mechanisms exist to describe the way information workers in organizations co-ordinate their activities. One of these mechanisms is *direct supervision*, which in our view can be applied to the co-ordination between dispatcher and driver. Direct supervision means that one person takes responsibility for the activities of others, issuing instructions to them, and monitoring their actions. Direct supervision can be described in terms of the information paradigm depicted in section 1.3. Two or more RS/IS-combinations are considered to be one RS-component, where the higher level IS-component issues instructions to the lower level IS-components and monitors their actions (Bots 1989, pp. 22-23). Applying this concept to our problem area, this means that a transport combination can be split into the driver, forming the lower level IS-component, and the equipment, forming the lower level RS-component, this is represented graphically in figure 3-20.

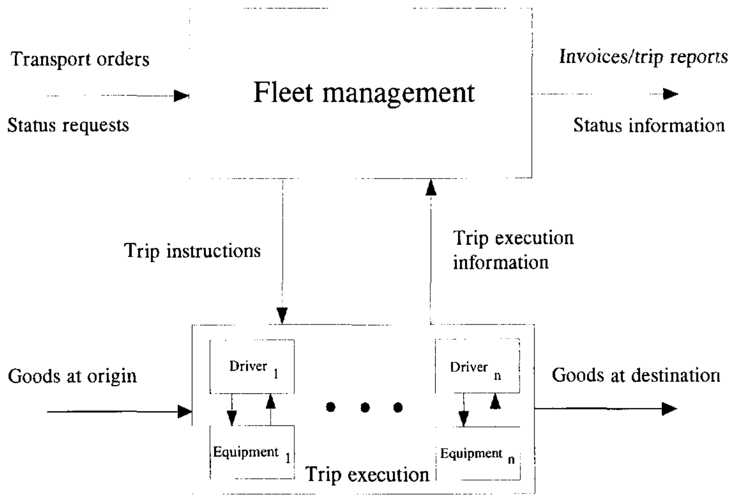

Figure 3-20 Direct supervision in terms of RS/IS-combinations

The activities of the driver can be divided into two categories: activities relating to the driving and handling of equipment and activities relating to the co-ordination with the dispatcher. The task analysis described in section 3.4 will be used to model these activities. The co-ordination between dispatcher and driver is modelled using the signal primitive described on page 48.

Figure 3-21 depicts the task EXECUTE TRIP and represents the execution of a trip starting with the receipt of the new instructions for the driver, and ends with signalling to the dispatcher that the current trip assignment is finished. Having received his or her new instructions, the driver drives empty to the loading location (*deadhead*), where the cargo will be loaded; if there is more than one loading location the driver will also pick up loads from these. Next, the driver drives to the unloading location where the cargo will be unloaded; if further cargo has to be unloaded, the driver will also drive to the other unloading locations. When all loads are unloaded, the driver will signal the dispatcher that the assignment is completed.

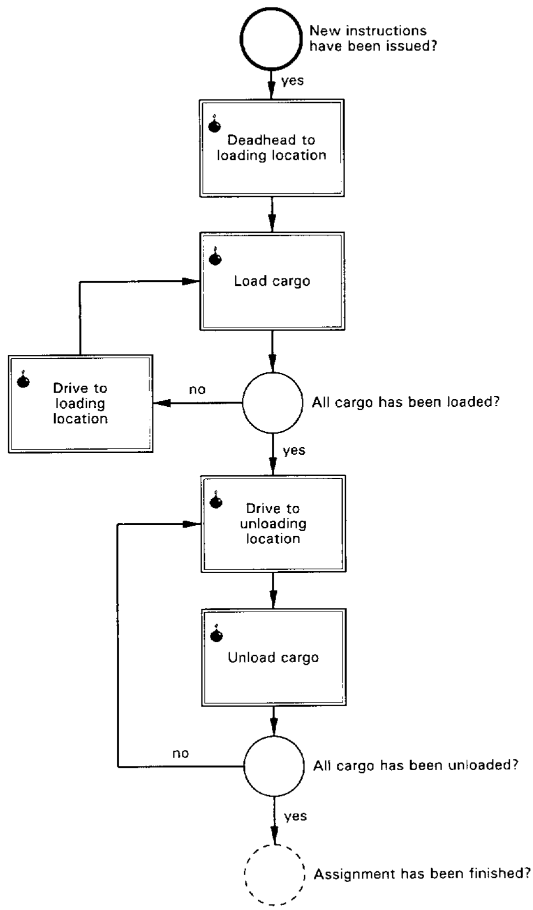

Figure 3-21 Task EXECUTE TRIP

Loading or unloading of cargo may require the transport combination to be changed. If a load was previously loaded on an interchangeable transport unit at the loading or unloading location, a driver will be instructed to pick up the loaded unit and leave an empty unit behind for the next load from that particular location. A driver may be confronted with two kinds of problems during loading or unloading: a load to be picked up or to be delivered may not be accepted at the loading or unloading location, or loading or unloading of the cargo may be delayed. The most likely cause for refusing to load or unload a cargo is that pickup or delivery of the load has not been announced by the customer to the loading or unloading location. In the case that a problem occurs during loading or unloading, drivers are instructed to make a telephone call to the planning department to report the problem and the possible cause.

Figure 3-22 shows the task structure for the task LOAD CARGO. The task structure for UNLOAD CARGO is not included in the description of the trip execution model, because of its similarity in structure to the task LOAD CARGO.

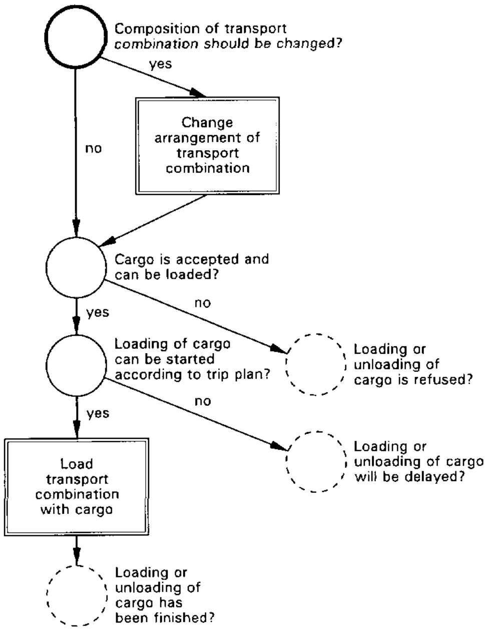

Figure 3-22 Task LOAD CARGO

A task structure has been designed for driving between the loading and unloading locations that takes into account the driving time regulations a driver has to adhere to, and the existence of frontiers in Europe. After a driver has driven the transport combination for a certain time, he or she must stop driving and take a rest before continuing the trip. A driver is not allowed to exceed a limited number of driving hours per day. When crossing a frontier, the transport combination has to go through customs. This means that, if the transport combination is loaded with cargo, the cargo must be cleared at the frontier.

If delays or problems occur during trip execution, the driver must report these exceptional conditions to the dispatcher. The task structure for DRIVE TO UNLOADING LOCATION is shown in figure 3-23. As the task structures for deadheading to a loading location and driving to a loading location are similar to the structure for driving to an unloading location, only this task structure is presented.

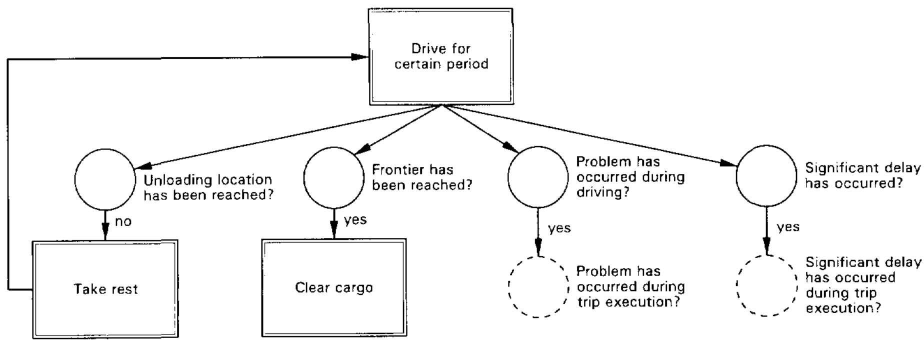

Figure 3-23 Task DRIVE TO UNLOADING LOCATION

3.6 Problem Description

The fleet management process described in this chapter, has to cope with a number of problems. As part of our descriptive conceptual model, we present a list of the most important and most common problems found in the planning departments of the three haulage companies investigated. Although the problems we found were not all the same within our three case-studies, we present a problem description in this section, indicating problems that should be regarded as "common denominators" for problems relating to fleet management in professional FTL road transport.

- The mean interval between placement of a transport order and the requested starting time of the order narrows, giving the dispatcher less time to find adequate assignments to carry out the transport order.
- At present, road haulage companies find that the distances covered by unloaded transport combinations are too high giving rise to low load factors, however there are no statistics to support this.
- Punctuality regarding requested loading and unloading times is becoming more and more an issue. According to customers, loads are often picked up or delivered too late.
- Trip execution faces a lot of disturbances and unforseen events, that cause delays that can not be anticipated. Congestion in everyday traffic makes it difficult to

estimate driving times with sufficient accuracy. Furthermore, the duration of the loading and unloading processes is tending to become more difficult to predict, introducing more uncertainty in trip execution.

- Only a limited number of dispatchers in the planning department have the precise knowledge about the fleet management process needed to make up a trip plan. When one or more of these dispatchers is absent or resigns from the haulage company, determining the trip plan becomes a problem.
- When using interchangeable transport units or utilizing a large number of trailers, tracing equipment can become a difficult and complex task, requiring considerable time to perform.
- A number of problems are induced by using the terrestrial telephone network system:
  - Using the telephone demands a lot of both the dispatcher's and the driver's time, resulting in less efficiency of tasks.
  - Trip execution data is received too late or is incomplete, causing the administrative settlement of the trip in question to be delayed.
  - A driver cannot be reached in an active way to request information or change instructions. The dispatcher must wait for the driver to make a telephone call to the planning department. Thus, the execution of several tasks is postponed until the driver calls, resulting in a lot of overwork.
  - Giving instructions over the telephone system produces a lot of errors in the information exchanged between dispatcher and driver, causing misinterpretation of instructions and trip status updates.
  - Because the driver can not be instructed at an arbitrary moment, rush orders can be lost. If a driver is unassigned to a trip at a particular moment, a rush order the driver in question could very well carry out, can not be accepted.
- Co-ordination and tuning of tasks between dispatchers is very time-consuming and error-prone.
- The planning department is only manned during part of the day, while drivers should be able to supply information on a 24 hour basis.
- Administrative settlement of trips is very time-consuming, is often incomplete, and frequently lags behind.

The list presented above provides an inventory of the problems that have been identified in the planning departments of the three haulage companies involved in our research. The problems identified should be regarded as the "symptoms" of the origins of problems fleet management has to cope with. In section 4.2, a *support analysis*, to specify the support to be given to the dispatcher's tasks, is presented.

CHAPTER 4

DESIGNING A FLEET MANAGEMENT SYSTEM

4.1 Introduction

While the previous chapter presented the descriptive conceptual model for fleet management in road transport, this chapter will deal with constructing the *prescriptive* conceptual model for fleet management. This model will suggest improvements to the existing situation in fleet management by trying to provide solutions to the problems identified during problem analysis. As a starting-point in search of alterations to the existing way of working, the application of a mobile communication system to be used in conjunction with an information system to support the fleet management tasks of the dispatcher will be considered. The prescriptive conceptual model that is developed during the course of this chapter, will include the answer to the first research question:

> *What are the characteristics of an information system that makes use of mobile communications for supporting the fleet management process?*

This research question is directed to defining the "blueprint" of a new information system incorporating mobile communications, intended to support fleet management tasks by providing two-way message exchange, will be referred to as a *Fleet Management System* (Schrijver and Sol 1992, p. 125).

In section 4.2, a support analysis is presented, i.e., analyzing the symptoms of the problems described in section 3.6 leading to the actual problems to be approached in constructing the prescriptive conceptual model. Section 4.3 describes the concept of *real-time fleet management*, which can be defined as performing fleet management with access to real-time information regarding fleet movements and operations. Section 4.4 presents the layout for the Fleet Management System.

4.2 Support Analysis

In chapter 3, we provided a detailed insight into the fleet management process as it exists nowadays. We concluded the general description of the existing situation regarding fleet management with a problem description, featuring the problems encountered during analysis of the three case studies. Combining the task analysis and the problem analysis should lead to identification of the tasks that call for improvement. In this section, we will specify in which way support can be offered for task execution by dispatchers. Specifying support for the execution of tasks serves as the "link" between decisions to be made and the information technology to be applied (Bots 1989, p. 40).

The method to be followed to specify the support that mobile communications can provide for fleet management, will be referred to as *support analysis*. Support analysis consists of the following four steps:

1. Revisit the problems found;
2. Identify problem tasks using the list of problems;
3. Redesign current tasks, if desired or urged by the results of the problem analysis;
4. Specify support for resulting tasks, both existing ones and the ones redesigned in step 3.

In section 3.6, we made an inventory of the problems in fleet management. This inventory gives an overview of what can be regarded as the "symptoms" of the origins of the problems fleet management has to cope with. To reveal these origins, the problems identified in section 3.6 have to be revisited. The key problems of performing fleet management can be delineated as follows:

- Disturbances and unforseen events introduce uncertainty in trip execution. Due to stochasticity, the dispatcher is not able to anticipate to these interruptions appropriately in all cases and because of the geographical spread in the activities of the dispatcher and the driver and the limited number of occasions for communication between dispatcher and driver, a discrepancy between the perceived trip execution status and the actual trip execution status arises.

- Tasks for registration of trip execution data and administrative settlement of trips are time-consuming and error-prone. Invoicing of transport orders is often delayed while additional time is required for filing and closing the transport dossier in question.

- A problem exists in the availability of information. One, the dispatcher has acquired a lot of implicit knowledge which he or she has built up from daily practice over a number of years. It is very difficult - if not impossible - to make this information explicit. Two, during the course of trip execution, a lot of data has to be processed and exchanged among the dispatchers employed at the planning department, needing much time and synchronized co-ordination.

- Communication with the driver is time-consuming, subject to failures and misunderstandings, and can not be initiated at an arbitrary moment by the dispatcher. Further, dispatchers are generally only present at the planning department during regular office hours, whereas the trip execution process goes on for 24 hours a day.

- In many cases, dispatchers do not succeed in providing adequate information to customers or (un)loading locations concerning regular trip execution status updates, problems, or delays.

To solve the aforementioned problems, one should first investigate if tasks can be redefined or the co-ordination and sequencing of tasks can be altered. After all alternatives for *re-engineering* the current way of working have been examined, *support* should be specified for tasks whose execution is hampered by the problems listed above.

Recently, several authors have stressed the importance of re-engineering existing business processes (Davenport and Short 1990, Dur 1992, Hammer 1990). They argued that the integration of *business process redesign* and the application of information technology can lead to improvements in the performance of business processes not gained before. The use of information technology will enable the organization to be designed more effectively, abandoning existing structures and processes. The information technology we propose to apply for support of fleet management, is mobile communication technology. As we have argued in chapters 1 and 2, utilizing mobile communications for support of fleet management operations seems a promising approach to solve problems in fleet management. As mobile communications offer the possibility of two-way instantaneous communication, the degree of contact between dispatchers and drivers can be improved.

Hammer (1990, pp. 108-112) proposes a number of general organizational design principles to be applied when re-engineering existing business processes. Although not all these design principles are applicable to the fleet management process, three of these principles have been found to contribute to re-engineering fleet management activities:

1. *Subsume information-processing work into the real work that produces the information.* The planning department must deliver complete and accurate trip execution data to the invoicing department instead of having the invoicing department collect and process incomplete data created by the planning department.

2. *Put the decision point where the work is performed, and build control into the process.* By having the driver monitor his or her own work and providing him or her with a mobile communication system to report any (expected) exceptions immediately and easily, the dispatcher's tasks can be mainly limited to handling exceptions.

3. *Capture information once and at the source.* Data concerning trip status updates and trip execution must be captured at the source, which is the transport combination, and without human intervention be recorded in the planning department's information system.

In the sequel of this section, these three design principles will be applied in the redesign of the current tasks and the specification of the support to be provided for the resulting tasks.

If mobile communications is used to substitute the calls drivers make to the planning department, information between dispatcher and driver can be exchanged at the moment communication is called for. As a consequence, the way dispatchers and drivers work with respect to maintaining mutual contact will change, and therefore the task structures for passing on and receiving messages must be modified.

In figure 4-1, a modified task structure for receiving messages from the transport combination is shown. It is derived from the task structure in figure 3-13 which shows the task HANDLE MESSAGE FROM TRANSPORT COMBINATION. When these structures are compared, a significant difference can be seen. Instead of being restricted to sending messages at particular moments during trip execution, a transport combination has the possibility of sending trip status updates at arbitrary points in time. In principle, it is possible to send these updates continuously.

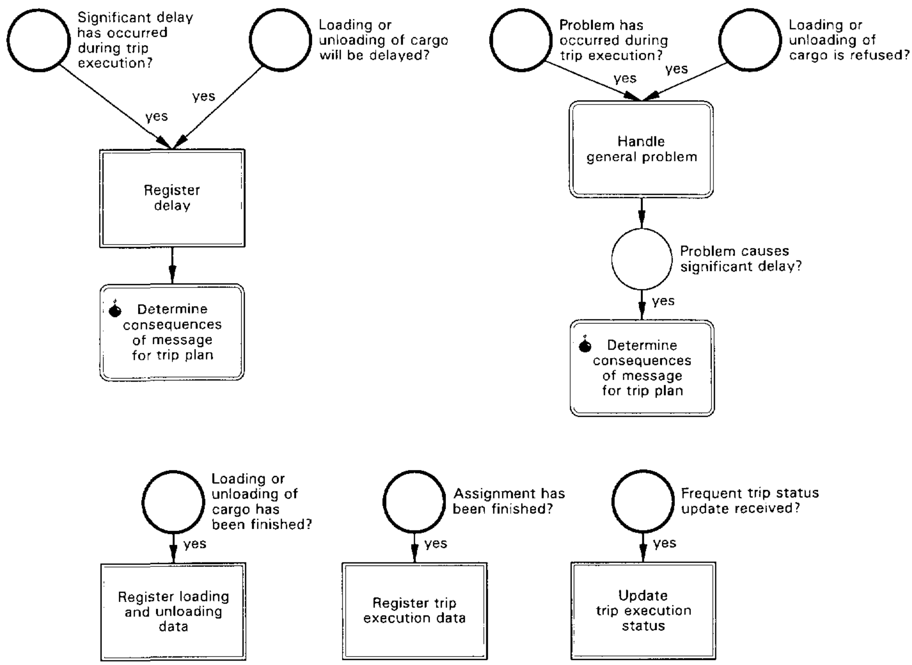

Figure 4-1 Modified task HANDLE MESSAGE FROM TRANSPORT COMBINATION

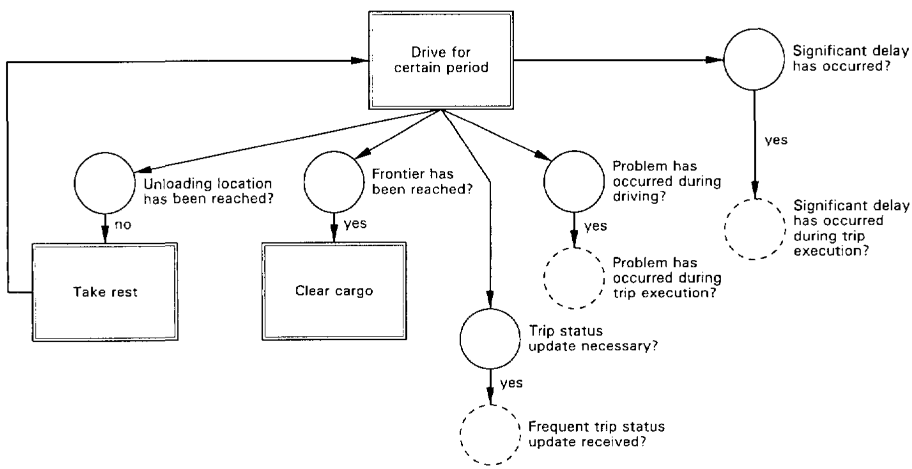

Figure 4-2 Modified task DRIVE TO UNLOADING LOCATION

The enhanced trip status updating shown in figure 4-1 has also resulted in a modification of the task structure for driving the transport combination. In analogy to section 3.5, the modified task structure for the task DRIVE TO UNLOADING LOCATION is depicted in figure 4-2 as an illustration of driving-type activities in the trip execution process. This task structure also serves as a specimen for making modifications to the tasks concerning loading and unloading, when frequent trip status updates can be made more frequently due to the introduction of mobile communications.

What is not directly expressed in figure 4-1 and 4-2, but is implied by making use of mobile communications, is a more dependable, more frequent, and more controllable stream of messages between dispatcher and driver. This enhanced information exchange is made possible by being no longer dependent on the terrestrial public telephone system. Although this does not lead to re-engineering of tasks within a task structure, the task COMMUNICATE INSTRUCTIONS TO DRIVER can be supported by being able to issue instructions to the driver at any moment. The task INFORM CUSTOMER ABOUT DEVIATION, that forms part of determining the consequences of a message for the current trip plan, can be performed more adequately, when status updates arrive at more frequent arrivals allowing for provision of more timely information to the customer.

Coping with uncertainty in trip execution requires taking into account the actual trip execution status and the current locations of transport combinations when preparing a provisional trip plan. As the information concerning trip execution status and locations of transport combinations is not very timely or accurate in the existing situation, due to the observed discrepancy between perceived trip execution status and actual trip execution status, and the inability of the dispatcher to anticipate disturbances in the trip execution process, it is very hard to reduce uncertainty during provisional trip planning. The same holds for the tasks IDENTIFY INAPPROPRIATE TRIP ASSIGNMENTS and EXCHANGE INAPPROPRIATE TRIP ASSIGNMENTS, where actual information about trip execution status and locations is even more important, because of the smaller interval between the time of assignment of a trip and the actual starting time of a trip.

The three aforementioned tasks, the performance of which declines due to inaccurate and non-actual trip status information, can be supported by (1) providing accurate, reliable, and timely trip status information, and (2) providing a mechanism which supports the estimation of finishing times of trip assignments, utilizing continuous trip status and location updates. Accurate, reliable, and timely information can be provided continuously using mobile communications between dispatcher and driver.

The problem of administrative settlement of trips can not be easily linked to the execution of one particular task. Administrative activities, such as registration or manipulation of data, are performed by the dispatcher during various phases of the fleet management process. The tasks for registering loading, unloading, and trip execution data, should be given special attention. Using mobile communications enables these tasks to be executed more effectively as the driver has a direct communication link at his or her disposal. If the information that comes from the driver is structured using data messages formatted in a certain manner, efficiency of information exchange can also be improved.

In general, support should be specified for administrative activities, such as the settlement of trips, registration of transport orders, the registration of planning data, and the registration of loading, unloading, and trip execution data as has been discussed in the previous paragraph. We concluded from our problem description that dispatchers spend a considerable amount of time on carrying out administrative tasks. The same observation was made in previous research aimed at providing support for dispatchers in comparable planning situations (De Jong 1992, Van Weelderen 1991, Verbraeck 1991).

Problem	Problem task(s)	Support
Uncertainty in trip execution	Prepare provisional trip plan Identify inappropriate trip assignments Exchange inappropriate trip assignments	Frequent trip status updates
Administrative settlement of trips	Settle trips Register trip execution data	Central registration of data Structured data exchange
Availability of information	Gather missing information Consult other dispatchers	Central registration of data Structured data exchange
Communication with driver	Instruct driver Handle message from transport combination	Mobile communications
Informing customer or location	Inform customer about deviation Provide customer with requested information	Frequent trip status updates

Table 4-1 Summary of problems, problem tasks, and proposed support

The fact that information of relevance to the trip planning task is unavailable to the dispatcher has been identified in our problem description of fleet management. When support of administrative activities is established, the availability of this information will be improved. In the case of central registration of different data, not seen in the existing situation, the supply of information for different purposes will be enhanced. As a result, the tasks GATHER MISSING INFORMATION and CONSULT OTHER DISPATCHERS will be executed less frequently. It should be stressed, however, that central registration of order and trip execution data only partially will contribute to making the dispatcher's implicit knowledge more explicit.

Improvements in the availability of trip planning information with regard to loading and unloading, and trip execution data, will lead to better information becoming available to inform the customer, customer information is at present a problem area.

Table 4-1 summarizes the key problems, the tasks in which the problems manifest themselves, and the support that can be provided for solving these problems.

4.3 Defining Real-Time Fleet Management

From the description of the existing situation of fleet management in professional road haulage and the support analysis presented in the previous section, it has been made clear that providing *feedback* from the trip execution process is an important prerequisite allowing dispatchers to perform their activities in an optimal way.

From a control-theoretic perspective, feedback could be defined as performing a comparison of the outputs with the desired output, with any difference causing an input to be sent to the process to adjust the operations in the process so that output will be closer to the desired output (Davis and Olson 1985, pp. 315-316). Passino and Antsaklis (1989) propose a feedback planning system extended by *situation assessment*. Through the existence of a feedback connection that allows for monitoring plan execution and replanning, the feedback planning system has the ability to recover from plan failures caused by disturbances during plan execution. Execution monitoring uses the domain state estimation and the problem domain inputs to ascertain whether plan execution is still on schedule.

Performing fleet management is done in a dynamic, uncertain, and time-critical environment, which Passino and Antsaklis (1989) refer to as a *real-time environment*. In this type of environment, a continual possibility for replanning must exist, as plan execution may be influenced heavily by disturbances. Therefore, the execution monitoring part of the feedback system must be able rapidly to detect deviations from the current plan. To accomplish better performance of execution monitoring, situation assessment is introduced. The situation assessor uses the problem domain inputs, outputs, and model to determine the state of the plan execution. A schematic depiction of the feedback planning system with situation assessment is presented in figure 4-3.

The situation assessor uses the control actions and the measured outputs to estimate the domain state which is involved in the execution monitoring and the plan generation process. When we translate this to the fleet management problem, this means that the situation assessor should be able to make an estimate of the trip execution status based upon trip assignments and trip status updates. Further, the trip execution status estimate can be used for trip execution monitoring and (re)scheduling of trip assignments.

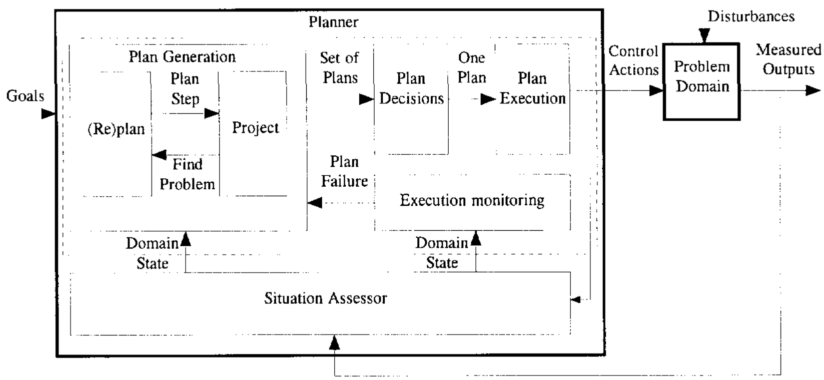

Figure 4-3 Feedback planning system with situation assessment

The situation assessment we propose to introduce into fleet management will consist of (1) providing frequent trip execution status updates to the dispatcher, (2) providing trip execution status estimates by the driver, both on a regular basis and in case of disturbances, i.e., delays and unforseen events, and (3) providing support for the dispatcher to handle the incoming updates and estimates (cf., Beroggi and Wallace 1991). Compared to the existing situation, where the terrestrial telephone system is used, mobile data communications enable the situation assessment to perform better, since drivers have more opportunities to pass on trip status information, and trip status information can be (partially) handled automatically by the system that supports fleet management. Sprague (1987) argues that a system that provides support for performance of Type II tasks should include functions for tracking, monitoring, and alerting. As a Fleet Management System supports the dispatcher performing his or her fleet management tasks, we assume these functions also to be included in the Fleet Management System.

To be able to alert the dispatcher to deviations in the trip execution process, the fleet management support system should be capable of interpreting the messages sent by the drivers and to transform these messages into useful trip execution information for the dispatcher. Therefore, a *management-by-exception* principle will be applied to provide support for the fleet management process (Thierauf 1982, p. 63). Introducing this general management principle into fleet management should allow for adequate trip execution monitoring and deviation alerting without overloading the dispatcher with too much (unessential) information (Schrijver and Sol 1991a).

In this section, a formalized description of real-time fleet management will be presented, based on the trip assignment problem for FTL transport with a restricted form of trip consolidation we introduced in section 3.1. This model will allow for a description of the requirements trip assignments should meet. When representing the trip assignment problem, one should realize that the assignment problem described stretches out over a certain period of time, the *planning horizon*. Therefore, planning in most transport companies is performed on a rolling basis. This implies that the trip assignment problem only represents a snapshot of the assignment problem within the planning horizon.

The formalized description for real-time fleet management also defines the way trip status updates and estimates should be dealt with according to the management-by-exception principle. Trip status updates and estimates are compared to the trip schedule to determine whether significant deviations from the trip schedule have occurred. If this is the case, violations will be signalled to the dispatcher.

The definition of real-time fleet management is described in a formalized way to provide a clear and unequivocal definition of the management-by-exception principle. This principle will be used to devise a layout for the Fleet Management System. This layout consists of several support components, the specification of which is dependent on the definition of real-time fleet management presented in this section. It should be emphasized that this section is aimed at providing a prescriptive definition of real-time fleet management for FTL transport (including a restricted form of trip consolidation) and therefore we may abstract from reality in some cases.

As we have shown in chapter 3, transport combinations are available to carry out the actual movement of cargo. A transport combination will be regarded as the primary *resource* to be assigned to a trip in the trip assignment problem. It should be noted that a transport combination consists of a number of secondary transport resources, such as drivers and trucks, which can cause the transport combination as a whole to become unavailable of one of the components becomes unavailable. The transport combination should be viewed as a *continuous resource type*, because the combination is available during a certain time interval for carrying out trips (Verbraeck 1991, p. 27). These concepts are formalized in definitions 4-1 and 4-2.

As we are only interested in the current trip plan, i.e., all trips scheduled before the planning horizon, only one availability interval of a transport resource is mentioned in definition 4-1. We assume that if a transport resource is available during more than one interval before the planning horizon, only the earliest interval is of interest.

Definition 4-1

A *transport resource* is an instance $r \in R$, and

- *resource_available* : $R \times T \rightarrow \{0,1\}$ is a function,

where:

- R is the set of resource instances (drivers, trucks, trailers, and interchangeable transport units) that can be brought into action in the trip execution process;
- T is the set of time instances;
- $t \in T$, indicates a specific time instance;
- $[t^S_i \,..\, t^E_i]$ denotes the interval in which transport resource i is available, with starting point t^S_i and ending point t^E_i;
- *resource_available*$(r,t) = 1$ if $t \in [t^S_r \,..\, t^E_r]$, else equals zero.

Definition 4-2

A *transport combination* $\underline{tc}$ is a vector $\underline{tc} = (r_1, \ldots, r_n) \in \boldsymbol{R}^n$, and

- *combination_available* : $\boldsymbol{R}^n \times T \rightarrow \{0,1\}$ is a function,

where:

- n is the number of transport resources that build the transport combination $\underline{tc}$;
- $\boldsymbol{R}^n = R \times \ldots \times R$;
- *combination_available*$(\underline{tc},t) = 1$ if $\forall\, i \in 1..n$: *resource_available*$(r_i,t) = 1$, else equals zero.

Since assigning trips to transport combinations has to take into account the distance to be driven between two locations, a function δ for determining the distance between two locations is introduced.

Definition 4-3

The *distance* δ between two locations l_i and l_j is defined using the following function:

- $\delta : L \times L \rightarrow \mathbb{R}$,

where:

- L is the set of locations involved in the trip assignment process;
- $l_i, l_j \in L$, $i \neq j$, are the two locations the distance is defined between;
- $\delta(l_i, l_j)$ returns the distance between the locations l_i and l_j.

A straightforward method for determining the distance between two points is to calculate the *euclidean distance* between the two points, using their respective coordinates (Assad 1988, pp. 37-38). As it is obvious that a transport combination has to make use of the road network for driving between locations, the euclidean distance does not represent an exact reflection of the real distance to drive. To obtain an estimate of the real road distance $\delta(l_i,l_j)$, the euclidean distance $\delta_e(l_i,l_j)$ has to be multiplied by a *circuity factor* γ (Love and Morris 1972):

$$\delta(l_i,l_j) = \gamma \cdot \delta_e(l_i,l_j) \tag{4-1}$$

Several successful applications of the use of the corrected euclidean distance have been reported in the literature (Ballou 1991, Brimberg and Love 1992, Fildes and Westwood 1978, Mathews and Waters 1986). Reliable values for the circuity factor γ within a specific region have been found using actual road distances. This method, however, also has a serious drawback, the applicability of the corrected distance method is limited by geographic characteristics and the possible existence of conurbations in the region involved. Accurate estimation of distances may be disturbed by the existence of downtown and suburban areas and natural obstacles, such as rivers and mountain ranges.

Another method for determining road distances between locations is making use of *road network files*. A road network file consists of an abstraction of the road network in terms of *nodes* and *links*. Nodes are locations where links begin or end. Links are the connections between two nodes usually representing roads, each with specific attributes such as length of road and road category (Lapalme *et al.* 1992). Road network files covering large areas, such as Europe and the United States, are nowadays available on a commercial basis (Jol 1992).

In fact it is not only the distance to be covered between two locations that is relevant in the trip assignment problem, the *time* a transport combination needs to cover the distance is also important. Naturally, this time depends primarily on the distance between two locations and the average speed associated with the part of the road network being used, but it is also dependent on local weather and traffic conditions, and the driving time regulations that the driver of the transport combination must adhere to.

Definitions 4-4 through 4-6 define the durations of times that are of interest in the fleet management process. These definitions have been mainly based on a description of a routing and scheduling application for buoy maintenance by the coast guard, presented by Cline *et al.* (1992).

Definition 4-4
The *travel time* τ^T between two locations l_i and l_j where activities are to be carried out, is the scheduled time for a transport combination $\underline{tc}$ to travel from location l_i to location l_j (including the time for crossing frontiers if encountered during travelling, the driver's rest periods, etc.) which depends on starting time t, and is defined using the following function:

- $\tau^T : \boldsymbol{R}^* \times L \times L \times T \rightarrow \mathbb{R}$,

where:

- $\tau^T(\underline{tc}, l_i, l_j, t)$ maps the distance $\delta(l_i, l_j)$ between locations l_i and l_j to the travel time needed to cover the distance for transport combination $\underline{tc}$ on starting time t.

The travel time is dependent on the average speed of the transport combination, the distance between the locations, and the starting time of travelling. The latter plays a role in determining the travel time because of driving time regulations the driver must adhere to, and because the amount of congestion depending on the time of day, may diminish the average speed of the transport combination. Real-time traffic information with respect to actual congestion and non-recurring road delays can also be used to adjust the scheduled travel time (Batz 1991).

The travel times are calculated between locations where certain activities must be carried out. These activities form part of a trip and are therefore explicitly contained in the trip schedule. Examples of these activities are loading and unloading.

Definition 4-5
The *servicing time* τ^S is the scheduled time needed to perform an activity required to carry out a transport order, where servicing time depends on the activity starting time t, and is defined using the following function:
- $\tau^S : L \times A \times T \rightarrow \mathbb{R}$,

where:
- A is the set of activities to be carried out;
- $a \in A$, is an activity;
- $l \in L$, is a location;
- $\tau^S(l,a,t)$ denotes the servicing time required for carrying out activity a on starting time t at location l.

The duration of the servicing time is considered to be dependent on the starting time of the activity, i.e., the time the transport combination arrives at the location where the activity has to be carried out and the location. Other dependencies, e.g., the type of cargo or the customer, are not included explicitly but are esteemed to be dependent on the activity itself.

Definition 4-6
The *servicing-and-travel* time τ^{T+S} is the time needed for transport combination $\underline{tc}$ to perform activity a at location l_a starting on time t and to travel to destination location l_d, and is given by the function:
- $\tau^{T+S} : \boldsymbol{R}^* \times L \times L \times A \times T \rightarrow \mathbb{R}$,

where:
- $\tau^{T+S}(\underline{tc},l_a,l_d,a,t) = \tau^S(l_a,a,t) + \tau^T(\underline{tc},l_a,l_d,t + \tau^S(l_a,a,t))$.

In section 3.5, a trip execution model for fleet management was developed. In this trip execution model several activities, e.g., driving, loading, and unloading, carried out by the driver was identified. De Jong (1992) defines these activities as *trip components*, i.e., "one or more activities, which are part of the trip execution, and which are regarded as an uninterruptible unit." In assigning trips to transport combinations, starting times of trip components play an important role, as they build up the schedule the driver has to follow. Furthermore, starting times are important in the schedule because customers may have imposed restrictions on the loading and unloading times. These restrictions will be referred to as *service requirements*. The definitions for a trip and a service requirement are given in definitions 4-7 and 4-8.

Definition 4-7
A *trip* σ is a sequence of N successive scheduled activities and is defined in the following way:
- $\sigma \equiv \langle (l_1,a_1,t_1), \ldots , (l_N,a_N,t_N) \rangle$,

where:
- $N \in \mathbb{N}$, is the number of activities to be carried out within one trip;
- $\forall\, i \in 1 \,..\, N\text{-}1 : t_i < t_{i+1}$;
- (l_i,a_i,t_i), $i \in 1..N$, is a 3-tuple denoting the scheduled performance of activity a_i on starting time t_i at location l_i.

Definition 4-8
A *service requirement* is a 4-tuple (l,a,t_S,t_E), which defines the requirement that the performance of activity a be initiated at location l within the interval $[t_S \,..\, t_E]$, where t_S denotes the earliest starting time and t_E the latest ending time. Whether a service requirement for activity a is met if the performance of the activity is started at time t, is denoted by the following function:
- $\rho : L \times A \times T \rightarrow \{0,1\}$,

where:
- $\rho(l,a,t) = 1$, if service requirement for activity a at location l is met if started at time t, else $\rho(l,a,t) = 0$.

Trip assignment deals with assigning trips to transport combinations. Therefore we define a function which "maps" a trip to a transport combination if a transport combination can be found to carry out the trip. As in trip assignment the next trip to be carried out by a transportation combination is also important, a successor function is also defined. The definitions are given in definitions 4-9 and 4-10.

Definition 4-9
A *trip assignment* is defined using the following mapping function:
- $\varphi : \Sigma \rightarrow \boldsymbol{R}^* \cup \varnothing$,

where:
- Σ is the set of trips;
- $\varphi(\sigma) = \underline{tc}$, meaning that the trip σ is assigned to transport combination $\underline{tc}$;
- $\varphi(\sigma) = \varnothing$, meaning that the trip σ is unassigned.

Definition 4-10

The *successor trip assignment* function is defined in the following way:

- $\varphi\bullet : \Sigma \rightarrow \Sigma \cup \varnothing$,

where:

- $t_{\sigma_{i,j}} \in T$, denotes the time activity j for trip σ_i starts;
- $\varphi\bullet(\sigma_i) = \sigma_j$, if $\exists\ \underline{tc} \in \boldsymbol{R}^n$, $\exists\ \sigma_i, \sigma_j \in \Sigma$:
  $\varphi(\sigma_i) = \varphi(\sigma_j) = \underline{tc} \wedge (t_{\sigma_{i,n}} < t_{\sigma_{j,1}}) \wedge (\nexists\ \sigma_k \in \Sigma \backslash \{\sigma_i, \sigma_j\} : t_{\sigma_{i,n}} < t_{\sigma_{k,1}} < t_{\sigma_{j,1}})$,
  meaning that the successor trip of trip σ_i is trip σ_j,
  or $\varphi^\bullet(\sigma_i) = \varnothing$, meaning that there is no successor trip of trip σ_i assigned.

The set of trip assignments, designated a *trip plan*, should be *feasible*, which means that the trip plan should comply with some requirements, warranting that the trip plan is practicable and that service requirements are met. These requirements are defined in definition 4-11.

Definition 4-11

A *trip plan*, formed by the set of trip assignments, is said to be *feasible*, if the following conditions are met:

1. All service requirements imposed by the customers are met:
   $\forall\ \sigma \in \Sigma,\ \forall\ i \in 1 \,..\, N_\sigma : \rho(l_{\sigma,i}, a_{\sigma,i}, t) = 1;$
2. The intervals between scheduled activities within one trip allow for performance of activities and travelling between locations:
   $\forall\ \sigma \in \Sigma,\ \forall\ i \in 1 \,..\, N_\sigma : t_{\sigma,i+1} \geq t_{\sigma,i} + \tau^{S+T}(\varphi(\sigma), l_{\sigma,i}, l_{\sigma,i+1}, a_{\sigma,i}, t_{\sigma,i})$;
3. Successive trips to be carried out by a transport combination should not overlap:
   $\{\ \forall\ \sigma \in \Sigma \mid \varphi\bullet(\sigma) \neq \varnothing\ \}$:
   $t_{\varphi\bullet(\sigma),1} \geq t_{\sigma,N_\sigma} + \tau^{S+T}(\varphi(\sigma), l_{\sigma,N_\sigma}, l_{\varphi\bullet(\sigma),1}, a_{\sigma,N_\sigma}, t_{\sigma,N_\sigma})$;
4. Successive trips to be carried out by a transport combination should not introduce too much idle time:
   $\{\ \forall\ \sigma \in \Sigma \mid \varphi\bullet(\sigma) \neq \varnothing\ \}$:
   $t_{\varphi\bullet(\sigma),1} \leq t_{\sigma,N_\sigma} + \tau^{S+T}(\varphi(\sigma), l_{\sigma,N_\sigma}, l_{\varphi\bullet(\sigma),1}, a_{\sigma,N_\sigma}, t_{\sigma,N_\sigma}) + \nu_{\text{idle}}$;
5. A transport combination assigned to a trip should be available for the time the trip is to be carried out:
   $\{\ \forall\ \sigma \in \Sigma \mid \varphi(\sigma) \neq \varnothing\ \}$:
   $\mathit{combination\_available}(\varphi(\sigma), t_{\sigma,1}) = 1 \wedge$
   $\mathit{combination\_available}(\varphi(\sigma), t_{\sigma,N_\sigma}) = 1;$

where:

- $l_{\sigma,i} \in L$, denotes the location activity i for trip σ takes place;
- $a_{\sigma,i} \in A$, denotes activity i for trip σ;
- $t_{\sigma,i} \in T$, denotes the time activity i for trip σ starts;
- N_σ denotes the number of activities to be carried out during trip σ;
- $\nu_{\text{idle}} \in \mathbb{R}$, is a predetermined threshold value, which denotes the maximum idle time.

Deviations between planned and actual schedule may cause the trip plan to be adjusted or other actions to be initiated. Application of the management-by-exception principle should assist the dispatcher in handling the incoming actual trip events and should provide a filter for actual trip events that have no consequences for the current trip plan. If the current trip plan is affected by an occurrence of an actual trip event, the trip assignment in question is said to be *violated.* To determine whether an actual trip event causes a violation, the feasibility requirements given in definition 4-11 will be used as a starting-point.

With respect to requirements 2 and 3 of definition 4-11, we would like to remark that these requirements are "hard" in the sense that they are required by logic. The other requirements are called "soft" in the sense that these requirements in some cases can be regarded as less tight. However, not fulfilling a requirement will have generally a negative effect on the cost and the service level of the trip plan.

Definition 4-12

A *deviation* Δ_a is defined as the difference between the scheduled time of an activity a and the actual time activity a has taken place or - probably - will take place. The deviation Δ_a can be calculated in four different ways, making use of different points of time:

1. Using the actual starting time of activity a:
   $\Delta_a = t^{AS}_a - t_a$;
2. Using the actual finishing time of activity a:
   $\Delta_a = t^{AF}_a - (t_a + \tau^S(l_a,a,t_a))$;
3. Using the expected finishing time of activity a as estimated by the driver, in the case activity a has already started:
   $\Delta_a = t^{EF}_a - (t_a + \tau^S(l_a,a,t_a))$;
4. Using the distance still to cover from a certain location when travelling from the previous location to location a:
   $\Delta_a = t_p + \tau^T(\underline{tc},l_p,l_a,t_p) - t_a$;

where:

- $t_a \in T$, denotes the scheduled time activity a has to take place;
- $t^{AS}_a \in T$, denotes the actual starting time of activity a;
- $t^{AF}_a \in T$, denotes the actual finishing time of activity a;
- $t^{EF}_a \in T$, denotes the expected finishing time of activity a;
- $\underline{tc} \in \boldsymbol{R}^*$, denotes the transport combination assigned to activity a;
- $t_p \in T$, denotes the time transport combination $\underline{tc}$ is located on location l_p;
- $l_a \in L$, denotes the location where activity a is to be carried out;
- $l_p \in L$, denotes the location transport combination $\underline{tc}$ is located on time t_p;
- Δ_a denotes the deviation between the scheduled and actual - or estimated - time activity a takes place as calculated according to the specification stated above. If no value for Δ_a can be calculated, then Δ_a is undefined.

So far, the trip assignment problem has been formalized with regard to the static aspects which are mainly relevant when preparing the provisional trip plan. However, performing fleet management also requires adjusting the trip plan during trip execution, thus including the dynamic aspects of assigning trips. The basis from which to describe the dynamics in fleet management is the *deviation* between *scheduled trip events* and *actual trip events*. The actual trip event is the occurrence of a real-time event during trip execution which may be, but not necessarily should be, related to a scheduled trip event. A scheduled trip event is an event explicitly included in the trip schedule, defining the scheduled occurrence of an event at a certain time. The definition for a deviation is given in definition 4-12. Figure 4-4 outlines schematically the five different time points that have been used to define a deviation in definition 4-12.

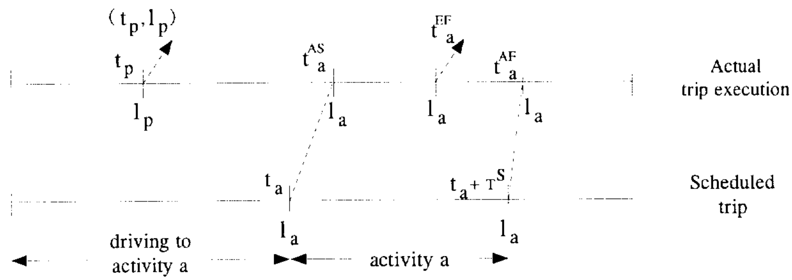

Figure 4-4 Time points used in determining deviation Δ_a

A schedule violation will occur when the deviation between a planned trip event and a corresponding actual trip event exceeds a certain threshold (see definition 4-13). In this case, the deviation is of such a magnitude that the dispatcher should be informed even if the violation will not have any impact on the current trip plan.

Definition 4-13
A *schedule violation* occurs as the deviation for an activity a exceeds a predetermined threshold value $\nu_{\text{deviation}}$, i.e., $|\Delta_a| \geq \nu_{\text{deviation}}$, if Δ_a is defined.

If a trip in execution is behind schedule, future service requirements may be violated. If the current trip schedule is assumed to be valid, using the most actual deviation or deviation estimate may lead to a violation detection of a service requirement concerning a future activity in the trip (see definition 4-15). An auxiliary function is introduced in definition 4-14 which adjusts the scheduled time for an activity using the most actual deviation of a previous, but actual, activity, if such an activity has occurred yet.

Definition 4-14
The function $\theta : A \times T \rightarrow T$ maps the scheduled time t for activity a to an expected time based on the most actual deviation in the preceding activities of activity a. If such a deviation does not exist, the function θ will map the scheduled time t onto itself:

- $\theta(a,t) = t + \Delta_a$, if Δ_a contains the most actual deviation, else returns t.

Definition 4-15
A *service requirement violation* will occur when for one of the activities in a trip a service requirement is violated when the most recent deviation occurred during the execution of the trip is taken into account:

- $\exists\, \sigma \in \Sigma, \exists\, i \in 1 \,..\, N_\sigma : \rho(l_{\sigma,i}, a_{\sigma,i}, \theta(a_{\sigma,i}, t_{\sigma,i})) = 0.$

Due to deviations between trip plan and trip execution, the requirements that two successive trip assignments do not overlap or introduce too much idle time (see requirements 3 and 4 in definition 4-11), may be violated. The trip assignment currently being executed that causes the violation will be called *inappropriate*. The definitions for the overlap violation and the idle time violation are given in definition 4-16.

Definition 4-16
A trip assignment $\varphi\bullet(\sigma)$ becomes *inappropriate* (as a consequence of actual occurrence of an activity of trip σ) if:

- an *overlap violation* occurs:
  $t_{\varphi\bullet(\sigma),1} < \theta(a_{\sigma,N_\sigma}, t_{\sigma,N_\sigma}) + \tau^{S+T}(\varphi(\sigma), l_{\sigma,N_\sigma}, l_{\varphi\bullet(\sigma),1}, a_{\sigma,N_\sigma}, \theta(a_{\sigma,N_\sigma}, t_{\sigma,N_\sigma}))$;
- an *idle time violation* occurs:
  $t_{\varphi\bullet(\sigma),1} > \theta(a_{\sigma,N_\sigma}, t_{\sigma,N_\sigma}) + \tau^{S+T}(\varphi(\sigma), l_{\sigma,N_\sigma}, l_{\varphi\bullet(\sigma),1}, a_{\sigma,N_\sigma}, \theta(a_{\sigma,N_\sigma}, t_{\sigma,N_\sigma})) + \nu_{\text{idle}}$.

If a trip assignment becomes inappropriate during execution of the trip plan, the dispatcher can attempt to reassign trip assignments already made, thus eliminating the inappropriate trip assignment(s) from the trip plan, This is carried out by exchanging trip assignments in such a way that a feasible trip plan is obtained. Figure 4-5 gives an example of exchanging two trip assignments, where one is inappropriate, yielding a (partially) feasible trip plan. The bold bar indicates the estimate of the duration of the current trip, obtained by applying the function θ to the last activity of the trip currently being executed. It should be noted that exchange of the two trip assignments is only possible if enough time is available for travelling from the ending location of the current trip to the starting location of the newly assigned trip.

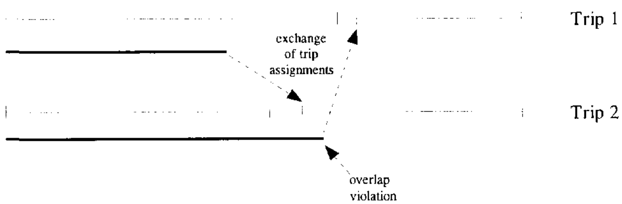

Figure 4-5 Example of exchanging inappropriate trip assignments

Due to backlogs arising during trip execution, a transport combination may not be available at the adjusted ending time of the trip assignment in question. In this case an *availability violation* occurs (see definition 4-17).

Definition 4-17
An *availability violation* with regard to trip σ will occur (as a consequence of actual occurrence of an activity of trip σ) if
- $combination\_available(\varphi(\sigma),\ \theta(a_{\sigma,N_\sigma}, t_{\sigma,N_\sigma})) = 0$.

4.4 A Layout for a Fleet Management System

In this section, the layout of a *Fleet Management System* (FMS) will be presented. The FMS should provide support for the performance of tasks related to fleet management by dispatchers. The layout for the FMS is based upon the support analysis we presented in section 4.2 and the definition for real-time fleet management that has been elaborated in section 4.3. The FMS is an example of a *planning support environment* (PSE) (De Jong and Sol 1991). A PSE can be seen as an environment where, in our case, the dispatcher is surrounded by - and interacting with - people, computers, the telephone, a mobile communication system, etc. (Bots 1989, p. 51). A PSE can be compared to a *decision support system* (DSS), these have been mentioned in the literature quite often to depict systems that support the tasks of an information worker. The major distinction between a PSE and a DSS is the emphasis on supporting planning processes in PSEs, which can be regarded as a specific case of the general decision making process. The term "environment" is used in preference to "system" because we look at the workplace the dispatcher is working in, and talking about an environment closely resembles the dynamic activities the dispatcher performs.

Using the definition of fleet management stated in section 1.3 and the characteristics of a planning support environment given above, a Fleet Management System can be defined in the following way:

> *A Fleet Management System is a real-time information based planning support environment for support of real-time planning, control, and monitoring of fleet movements and operations*

Our definition of an FMS is restricted to support real-time planning, control, and monitoring of fleet movement and operations, whereas other definitions of an FMS also include other functions, e.g., route guidance, cargo tracking, vehicle maintenance management, etc. (Both 1991, Hepworth and Ducatel 1992, Tanja 1990). It must be emphasized that these functions are excluded from the FMS layout we propose in this section.

The support analysis presented in section 4.2 and the description of real-time fleet management in section 4.3 result in several requirements for the FMS:

1. A *two-way mobile communication system* needs to be available in order to make mutual immediate contact between the dispatcher and the driver possible. Reliable message exchange between dispatcher and driver should be guaranteed within the area where the haulage company normally operates.

2. To enable structured information exchange, the mobile communication system should be able to transfer *data* messages (Kimbrough and Moore 1992, Vervest 1985). The use of data messages presenting information in a structured way enables the automatic handling of messages as the driver can send *preprogrammed messages*. Sending a preprogrammed message can be compared to completing a form; each field in the message has a certain format and meaning.

3. We have indicated in section 4.3 that determination of the current position of a transport combination allows for early signalling of, possible, violations. As manual position determination of the transport combination requires the involvement, and therefore duty time, of the driver and is error-prone, *automatic vehicle location* (AVL) reporting is preferred (Skomal 1981).

4. Introduction of direct mobile communications may result in an increase of the incoming message flow. To avoid overloading of the dispatcher, trip execution monitoring needs to be supported by *filtering* the incoming messages according to the management-by-exception principle presented earlier in this chapter (Davis and Olson 1985, p. 210). Only messages that cause a violation to occur and that contain important information for the driver should be let through. Preliminary investigations showed that applying a management-by-exception principle is regarded to be useful by road haulage companies (Bergkamp 1991).

5. It is apparent from the support analysis that centralized registration of driver, equipment, and transport order data is a necessity.

6. Although a lot of implicit knowledge is required for determining trip assignments, scheduling and rescheduling support should be provided as far as possible in order to diminish the time required to obtain essential trip execution information for performance of the trip assignment task. For examples of scheduling support utilizing real-time information, see Brown *et al.* (1987) and Powell *et al.* (1988).

7. Centralized and automated registration of trip execution data is necessary as trip execution information has to be made available to the dispatcher in a quick and facile manner. Furthermore, administrative settlement of trips can be supported.

8. Support for the administrative settlement of trips is needed for preparing invoicing data and generating management information to streamline the settlement of trips.

Following the requirements stated above we are now able to define the *support components* that constitute the Fleet Management System. A support component is the collection of means that are explicitly meant for facilitating the making and/or implementation of a decision. Therefore, we define the layout for the FMS in terms of support components (Schrijver and Sol 1991b). Three types of support components can be distinguished: support components for supporting Type I tasks, support components for supporting Type II tasks, and auxiliary support components.

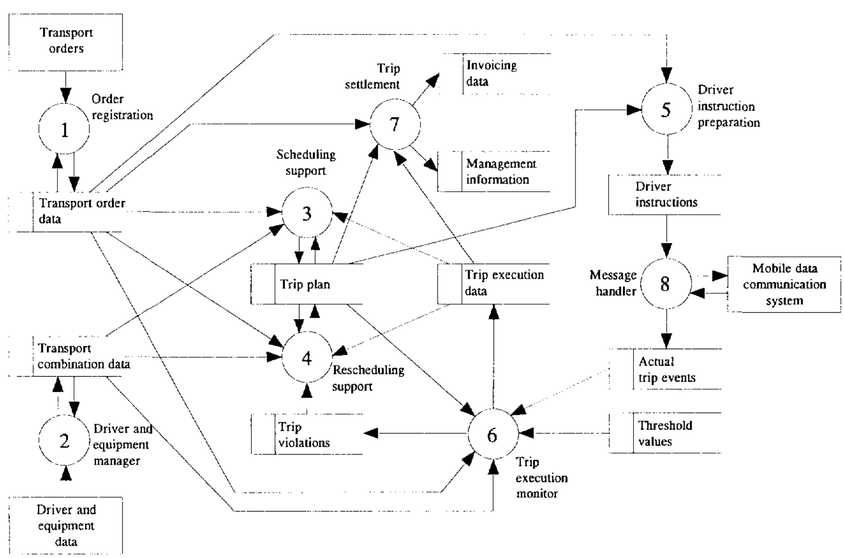

Figure 4-6 Layout of the Fleet Management System

A data flow diagram is used to present the support components and the relationships between the support components, and to delineate the layout of the FMS (cf., De Jong 1992, Verbraeck 1991). The support components are represented by circles. The numbers in the circles correspond with the numbers given in the description of the support components that follows the data flow diagram. The major information flows between the components have been included, but for the sake of clarity some flows have been omitted from the FMS layout. For instance, although location data are important for real-time fleet management, as can be concluded from section 4.3, they are not depicted in the layout as they are used by almost all support components. The data flow diagram for the Fleet Management System is presented in figure 4-6.

The proposed layout of the Fleet Management System consists of the following support components:

1. ORDER REGISTRATION. The registration of transport order, customer, and location data takes places in this support component. Moreover, support needs to be provided for making the decision whether or not to accept a transportation order. Therefore, an overview of already accepted transport orders and available transport capacity will be presented to the dispatcher, taking into account date, time, and loading location of the transport order being treated.

   Eliminating deficits or shortage of transport orders or equipment also has to be supported in this component by comparison of transport combination availability, the set of orders already accepted, and trip execution status.

2. DRIVER AND EQUIPMENT MANAGER. The driver and equipment manager is a support component offering administrative support for the registration of drivers and equipment and their availabilities. The arrangement and registration of transport combinations is also supported by this component.

3. SCHEDULING SUPPORT. The first decision to be supported in the scheduling support component is which transport orders should be consolidated in the case of LTL transport. Note that this decision does not always have to be made. Next, the preparation of the provisional trip plan is made. Support for initial assignment of drivers to transport combinations can be provided by presenting suggestions for trip assignments, based on both static information (transport order data, transport combination data, road networks, etc.) and dynamic data (trip execution status information). When no trips can be found to assign a transport combination to, suggestions should be presented about where the empty transport combination should be repositioned.

4. RESCHEDULING SUPPORT. If inappropriate trip assignments arise during trip execution, *rescheduling* of trip assignments is necessary to re-obtain a feasible trip plan. First, the inappropriate trip assignments should be notified to the dispatchers as soon as an overlap or idle time violation occurs. Second, trip assignments that possibly can be exchanged with the inappropriate trip assignments in order to eliminate the violations, must be determined and presented.

5. DRIVER INSTRUCTION PREPARATION. The driver instructions preparation comprises the preparation of trip instructions for the driver, the preparation of legal documents, such as waybills and custom documents, and instruction of the driver by use of the mobile communication system.

6. TRIP EXECUTION MONITOR. The trip execution monitor supports the dispatcher by providing trip execution status information and by showing trip plan violations. The trip execution monitor continuously performs a comparison between the trip plan and the actual trip events that originate from the transport combinations. According to the management-by-exception principle, actual trip events are transformed automatically to trip execution status information and the dispatcher will only be informed about the trip plan violations that have occurred.

7. TRIP SETTLEMENT. The trip settlement component prepares trip execution information for invoicing purposes. Trip execution information, together with transport order data, is used to determine the final transport charge. Excess transport costs are signalled and passed on to the customer. Furthermore, management information that can be derived from the trip execution data will be generated. Examples of this are summaries of loading and unloading times and violations of the trip plan.

8. MESSAGE HANDLER. The message handler establishes the link between the mobile communication system and the other components of the Fleet Management System. This component is responsible for performing several functions. Firstly, preprogrammed messages must be received and transferred to the trip execution monitor. Secondly, general message traffic, i.e., receiving, sending, presenting, and archiving of messages, need to be handled.

The information flows between the support components have been modelled in the layout for the Fleet Management System by *datastores*. The following datastores can be identified in the layout:

a. **TRANSPORT ORDER DATA**. Contains the required information of transport orders, customers, locations, and service requirements.

b. **TRANSPORT COMBINATION DATA**. Contains information on drivers and equipment that can be utilized in the trip execution process and their availability.

c. **TRIP PLAN**. Contains the trip assignments including scheduled starting, loading, and unloading times.

d. **DRIVER INSTRUCTIONS**. The instructions, and documents, that are needed by the driver of a transport combination to carry out the trip assignment according to schedule.

e. **ACTUAL TRIP EVENTS**. The actual trip events that have originated from the transport combinations during trip execution.

f. **THRESHOLD VALUES**. Threshold values determine whether a deviation between trip plan and trip execution will lead to violation occurrence or not.

g. **TRIP EXECUTION DATA**. Contains data about the actual trip execution, such as actual loading and loading times, expected times of arrival, etc.

h. **TRIP VIOLATIONS**. Contains the trip violations that have occurred during trip execution.

i. **INVOICING DATA**. Data needed for invoicing of transportation orders, including actual trip execution information and possible excess transport costs to be charged to the customer.

j. **MANAGEMENT INFORMATION**. Information that has been collected from trip execution data and that can be applied for management purposes, such as aggregated data of loading and unloading times and violations of the trip plan.

The datastores *a*, *b*, and *c* contain elementary, static, information that is of relevance for the fleet management process. When refining the information that comprise these datastores, the entity types that have been listed in table 4-2 can be found.

Refinement of datastores *d*, *i*, and *j* does not yield other entity types, as the datastores contain aggregated data. The datastores *e*, *f*, *g*, and *h* contain entity types that are mainly dependent on the implementation of the FMS (cf., Verbraeck 1991, p. 98). Chapter 6 presents another overview of the entity types based upon the implementation of a prototype for the FMS.

The dependencies between these entity types are represented using an *entity-relationship diagram* (see figure 4-7). Each transport order belongs to one customer and refers to carrying a certain product. Each transport order specifies cargo to be loaded and/or unloaded at a location. Drivers and equipment are arranged in transport combinations, to which one or more trips can be assigned. Each trip consists of one or more scheduled trip events, each related whether to a loading or unloading order. For each driver and piece of equipment, the available periods are contained in the data model.

a. **TRANSPORT ORDER DATA**	Customer Transport order Product Loading order Unloading order Location
b. **TRANSPORT COMBINATION DATA**	Driver Driver availability Equipment Equipment availability Transport combination
c. **TRIP PLAN**	Trip Scheduled trip event

Table 4-2 Elementary entity types in fleet management

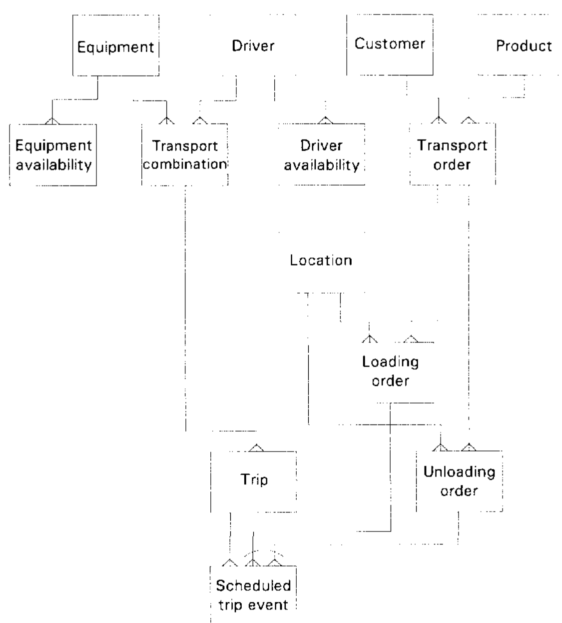

Figure 4-7 Elementary fleet management data model

CHAPTER 5

SIMULATION OF FLEET MANAGEMENT

5.1 Introduction

Chapter 4 presented the layout for a planning support environment for support of fleet management in road transport. A solution for support of fleet management was proposed based on a description of the existing situation in fleet management, an analysis of the problems encountered, and concepts from the literature. Chapter 4, therefore, answers the first sub-question raised in our proposal for research.

Once the layout for a fleet management system is established, issues concerning effectiveness and efficiency of using the fleet management system need to be raised. As the fleet management system has been developed to solve problems in fleet management, effects on performance of fleet management and trip execution need to be determined and compared with the situation as it exists today.

In this chapter, the effects of using fleet management systems on trip execution performance are investigated, answering the third sub-question of our research, which is repeated below:

> *What are the effects of using mobile communications on performance of the trip execution process?*

A *simulation approach* is applied to answer this question. Simulation can be used for understanding the behaviour of a system and/or evaluating various alternatives for the operation of a system (Shannon 1975). To determine the effects of using mobile communications on trip execution performance, the second objective of simulation is relevant. With the layout of the fleet management system available, we are able to compare the results of simulating the existing trip execution process with the results of the situation "to-be." Furthermore, we are able to evaluate various alternatives for using mobile communications, based on the properties of the FMS layout.

We believe that simulation of the fleet management and trip execution processes can contribute insight into the effects of using mobile communications on trip performance. Performing a simulation study also allows for the evaluation of various alternatives without disrupting the ongoing organization. Performing our experiments in a real-life situation was not possible at the time of our research as none of the Dutch hauliers within our field of interest had equipped the whole fleet with mobile communication terminals. In the recent past, several authors have employed simulation for modelling of road transport problems successfully (e.g., Cochran and Chen 1991, Cochran and Lin 1989, Kondratowicz 1990, Moore *et al.* 1991).

To conduct the simulation study, we follow the approach presented by Sol (1982). The following activities can be identified in our simulation study (see also Dur 1992):

- Conceptualization;
- Specification;
- Validation and verification;
- Experimentation;
- Evaluation.

Conceptualization deals with setting up a descriptive model of the existing problem situation within an organization in terms of object classes, and task structures. The result of this activity is a conceptual model of the existing situation. In fact, this activity corresponds to building the descriptive conceptual model presented in chapter 3, but carried out specifically for one haulage company.

Specification can be divided into specifying the *structural model* of the organization in question and specifying the *model system* (Dur 1992). Specification of the structural model includes refinement of object classes and task structures, if necessary, and instantiating objects. A model system can be viewed as the executable model which expresses the behaviour of the organization that is modelled. Specifying this model comprises the determination of the required input data for the model system, the measurement of sample data, analysis of data, and incorporating the definitive input data in the model system.

Specification of the descriptive conceptual model deals with identifying specific objects and tasks within one organization, and we choose to carry out this task for Rotterdams Tank Transport (RTT). RTT is one of the hauliers involved in the descriptive conceptual model, and is coping with a number of problems that relate directly to the communication between dispatcher and driver. Therefore, this choice seems to be justifiable. RTT's characteristic problems regarding effectiveness of fleet management can be summarized as follows (Babeliowsky 1992, Schrijver 1991):

- Deficiencies exist in the available information with regard to trip execution status;
- Trip plan quality can not be judged adequately;
- The extent to which drivers can be reached is insufficient;
- Crucial trip components have extensive durations;
- Considerable fluctuations occur in trip component durations.

Applying the simulation study to RTT and evaluating alternatives to performing fleet management will yield in a proposal for change and an insight into possible differences in efficiency of the trip execution process. To obtain these results, it is essential to model the dynamics of the fleet management and trip execution processes accurately (Sol 1992). The specification of the simulation model is addressed in section 5.2.

Verification and validation of the simulation model are necessary to ascertain whether the simulation model is a sufficient reflection of the organization that has been modelled. The results of this activity are presented in section 5.3.

Experimentation deals with designing alternatives for the existing organization. Devising these alternatives need to be aimed at solving the problems found in the organization. The results of simulating the "as-is" situation will be used as a guideline during the generation of alternatives. For each alternative, an experiment is designed for execution by the simulation model. The alternatives examined during the simulation approach are given in section 5.4.

The last activity in the simulation approach is evaluation of the results obtained from building the simulation model of the existing situation, and the results of performing experiments with alternative solutions. The evaluation of the simulation study is presented in section 5.5.

5.2 Specification

This section describes the refinement of the descriptive conceptual model and the instantiation of objects. These two activities must be carried out to construct a simulation model from the descriptive conceptual model.

The simulation model set up for RTT, is elucidated using an RS/IS-schema (see section 1.3). In figure 5-1, the real system depicted only differs slightly from the real system described in the descriptive conceptual model (see section 3.5). Trip components must be determined that correspond to activities carried out in the trip execution process that actually takes place within RTT. For instance, this means that an extra trip component needs to be included in the trip execution model that models the cleaning of tankers before the next trip can be started.

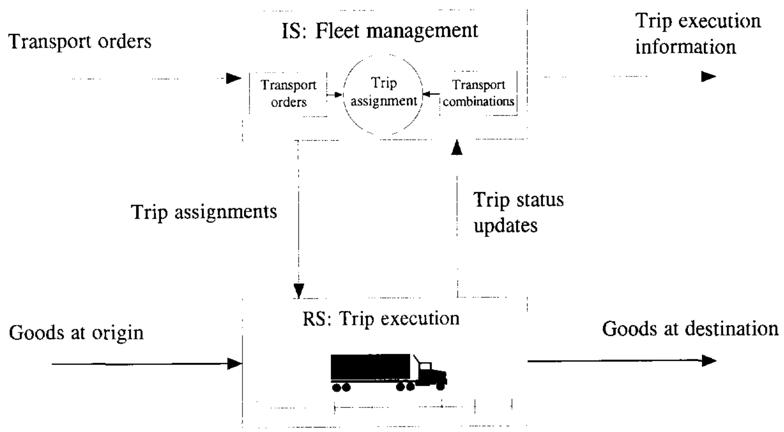

Figure 5-1 Layout of the simulation model for RTT

As we are interested in the effects of using fleet management systems on trip execution performance in this simulation study, it is not useful to model the fleet management tasks of the dispatcher *in extenso*. Therefore, we will for the moment regard all that take place in the planning department, including all activities from transport order acquisition to the administrative settlement of trips, as a black box using transport order information and trip execution status to generate trip assignments and to pass on trip execution information to the customer. In section 5.2.2, we will describe how the functionality of this black box is implemented in the simulation model.

The layout for the simulation model that results from this abstraction process is shown schematically in figure 5-1 (Babeliowsky 1992, p. 48).

To construct the simulation model, relevant data were gathered over a period of two months. Transport order data, data concerning availability and characteristics of transport combinations, and data about trip component durations were collected and analyzed in co-operation with the dispatchers at the planning department.

When building the simulation model, decisions must be made as to which part of reality should be modelled and which part should be left out of the model. This *abstraction and reduction* process is performed on a ongoing basis during the model specification activity. Validation of the empirical model needs to provide an answer to the question if the abstractions in the model are permissible.

The next three sections describe modelling of trip execution, modelling of fleet management, and the implementation of the simulation model in more detail.

5.2.1 Modelling Trip Execution

The definition of real-time fleet management provided in section 4.3 will be used as a guideline to describe the model of the trip execution process. This section explains several aspects of the trip execution model about which information is needed to perform real-time fleet management and the abstractions that are applied to the model will be argued.

A fundamental abstraction to be mentioned is the restriction to model only FTL transport. Although RTT does carry out some transport that involves loading at one location and unloading at two or more locations or the reverse - this only applies to about 5 percent of all orders for the period analyzed - the LTL transport is not included explicitly in the simulation model to prevent the model from becoming too complex. As only FTL transport is considered in the simulation model, a transport order relates directly to a trip and vice versa.

Modelling of product classes

RTT transports liquids and granulates utilizing equipment that incorporates one or more tank compartments. These are used for the actual transport of the liquid and granular goods. As the tank compartment is used again for the next order, in most cases, tank compartments have to be cleaned between successive trips. For the transport of some products, just cleaning the tank is not sufficient to make the tank suitable for transporting that particular product. Therefore, *product classes* were modelled in the simulation model. Each product to be moved is categorized and will fall in one particular product class. For the RTT case, ten product classes were defined. Product classes are categorized by the following characteristics:

- As *specific gravity* differs among the products and each piece of equipment has a specific capacity, information regarding the specific gravity of a product needs to be included in the trip assignment process.

- The allowed products loaded before, the *previous products*, have to be determined, an unsuitable previous product may preclude a trip being assigned to a transport combination that has carried the previous product.

- Products from some product classes can only be assigned to certain kinds of equipment.

Resources

Although several kinds of equipment are used for moving goods, we will use the transport combination as the resource unit to be assigned to a trip (see definition 4-2). To recall, a transport combination consists of a driver, a traction unit, and possibly a trailer and interchangeable transport unit(s). Analogous to the classification of product classes, a classification of transport combinations was set up, resulting in twelve *transport combination classes*. Transport combination classes are characterized by the following properties:

- The *capacity* of the transport combination. Capacity is of interest when determining whether an order can be carried out by a transport combination with regard to (possible) capacity restrictions.

- The *product classes suitable* for the type of transport combination used. As not all product classes may be loaded by a transport combination, the dispatcher has to determine whether a candidate trip assignment is allowable. A distinction must be made between candidate trip assignments that are strongly disapproved of, and candidate trip assignments that are inadmissible.

- The *presence of a special characteristic*. A part of the equipment operated by RTT, has a special characteristic, that customers may require to be present when carrying out a transport.

- The *type of equipment* used for transportation. Three distinctive kinds of equipment can be identified: chartered trailers and trucks, chartered containers, and equipment owned by RTT; because of the different operating costs of each type, the dispatcher must take into account the type of equipment, when determining trip assignments.

The availability of resources utilized in the trip execution process - the transport combination - is modelled using two tables. Each entry in the first table represents the identification number of the combination, the transport combination class, and the starting region for the transport combination. The second table models unavailability for a transport combination during the simulation period; each entry represents the interval a transport combination will be unavailable due to maintenance, hiring out of equipment, or legal inspections. The contents of these tables were based upon actual availability of transport combinations for the period simulated. These data were provided by the dispatchers of the RTT planning department.

Geographic modelling

As can be deduced from the definition of real-time fleet management presented in section 4.3, distances to be driven by the transport combinations are an important element in the fleet management problem (see definition 4-3). For the RTT simulation, these distances were modelled using *regions*. Instead of calculating distances between two specific locations, distances were determined using the distance between two regions, with each location situated in a certain region (Frowein 1990). To accomplish this, the area to be covered when carrying out transports was divided into smaller areas (regions) with a central location. To determine the distance between two regions, a matrix was set up containing the distances between the central locations of the regions. Distances covered within one region were determined by a constant value for the region, with the magnitude depending on the size of the region. For the RTT simulation model, over 40 regions in the western part of Europe were identified. The size of each region increases the further the region is from the RTT home base. (See figures 5-9 and 5-10 for an illustration of the division in regions.) Although the use of regions is not as accurate as using real road distances, it is believed that the results obtained will be valid as using regions closely corresponds to the current way of working by RTT's dispatchers.

Two additional matrices were constructed containing respectively routing information and information with respect to frontier crossings. Routing information is represented by a matrix in which each cell returns the next region to be traversed, the row depicts the current region and the column indicates the destination region.

Modelling of trip component durations

Trip execution can be viewed as consisting of a number of distinctive trip components, each with a certain duration. To ascertain that the simulated trip execution process corresponded as much as possible to actual trip execution, information concerning trip component durations and variances was incorporated in the simulation model.

The distributions used for defining the trip component durations were determined by analyzing data recorded by *digital trip data recorders*. A digital trip data recorder is an on-board truck device that records data concerning driver working hours, truck travel times and speeds, and other operating data (Taylor 1991). Digital trip data recorders record data with a high accuracy, are capable of collecting a large amount of data in an efficient way, and allow for automatic processing of the data. Nowadays, several types of digital trip data recorders are available in the Netherlands and are being used on a large scale (NEA 1990). All trucks owned by RTT are equipped with a digital trip data recorder. The data generated by a number of trucks were analyzed to obtain distributions defining the trip component durations, see Camp and DeHayes (1974).

We will now review the trip components that constitute the trip execution process at RTT, and present an analysis and a definition of the probability distributions of the durations for these trip components.

Travel time

To determine the time needed to travel from an origin location to a destination location - the travel time defined in definition 4-4 - three trip components are distinguished: *driving time*, *resting time*, and *frontier waiting time*.

Driving time includes the time needed to drive a certain distance. Short breaks - of less than one hour - are also contained in the driving time distribution. Due to driving time regulations, it is mandatory for the driver to take these breaks. The longer rests the driver must take are modelled separately. Analysis of the driving time data reveals the existence of a relationship between the distance driven and the average speed of the truck. Using a scatter diagram, it can be established that this relationship exists, but it is very difficult to express the relationship by one equation. Therefore, to model driving time adequately, three probability distributions are defined for modelling the driving times, selection of the one to be used for determining the driving time depends on the distance to be covered.

For example, figure 5-2 shows the sample distribution of the average speed of a truck for distances less than 50 kilometres, obtained from the recorded trip data. The probability distribution that is derived from the sample distribution also is depicted.

The probability distribution was determined by choosing a probability distribution function that seemed to fit the sample distribution frequencies on visual inspection and theoretical grounds (Pegden *et al.* 1990). Next, parameters were estimated for the distribution function based on the empirical data collected (cf., Ceric and Dobric 1989). To determine whether the empirical data differ significantly from the values that could be expected from the distribution function, a *goodness-of-fit* test was carried out using a Chi-Square (χ^2) and a Kolmogorov-Smirnov test (Hoover and Perry 1989, Neter *et al.* 1988, Pegden *et al.* 1990). To augment the statistical test applied to test the discrepancy between the sample distribution and the theoretical distribution, a graphical assessment of the fit between the two sets of data was carried out (Pegden *et al.* 1990). For a detailed account of the selection of the theoretical distributions and the results of the goodness-of-fit tests, see Babeliowsky (1992, pp. 213-220).

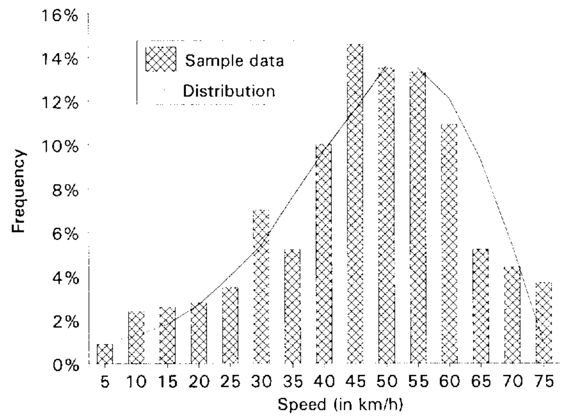

Figure 5-2 Distributions for average speed of truck (distance less than 50 km.)

Table 5-1 presents an overview of the probability distributions for the driving time durations. In the first two columns, the mean and standard deviation of the sample of real data are presented. The third column contains the probability distribution that resulted from the process described above. The function "Γ" stands for the Gamma distribution which is often used for modelling of distributions as it can take on a wide variety of shapes (Hoover and Perry 1989, p. 234). The two parameters define the scale and the shape of the function.

	mean	s.d.	probability distribution
distance below 50 km. (in km/h)	44.5	15.7	80 - Γ(6.9,5.1)
distance between 50 and 200 km. (in km/h)	59.6	14.0	90 - Γ(6.4,4.7)
distance above 200 km. (in km/h)	64.5	8.9	90 - Γ(3.1,8.3)

Table 5-1 Probability distributions for driving time durations

As mentioned before, a driver must adhere to the driving time regulations. According to these regulations, a driver has to rest for eleven hours when the maximum permitted driving time is reached. The rest period may be shortened to eight hours, under the condition that the remaining rest hours will be compensated for within a short time. Analysis of the RTT trip data yields an average resting time of ten hours and fifty-three minutes which is in very close accordance to the mandatory resting time. A set of rules is used to model the resting time of the driver, based on a standard rest period from 8:00 p.m. to 7:00 a.m. Rest may start later as the driver may have to finish his or her current activity first. If the driver has to load or unload before 7:00 a.m., the rest period will be shortened.

Finally, we discuss frontier waiting time, the third trip component influencing the duration of the travel time. Transport combinations have to go through customs frequently, most occasions a delay results due to the settling of customs documents taking time or as a result of faults in legal documents. As waiting time when crossing a frontier also depends on whether or not the transport combination is loaded, two distinctive probability distributions can be determined for crossing a frontier (table 5-2). The function "LogN" stands for the lognormal distribution which is widely used in simulation modelling to represent the time needed to perform manual tasks (Hoover and Perry 1989, pp. 236-237). The two parameters define the mean and standard deviation of the distribution.

	mean	s.d.	probability distribution
frontier waiting time in min. (loaded)	59.0	71.8	$\Gamma(60.0,1.0)$
frontier waiting time in min. (unloaded)	45.6	73.8	LogN(45.6, 73.8)

Table 5-2 Probability distributions for waiting times when crossing frontiers

Servicing times

In determining servicing times (see definition 4-5) for tanker transport, three trip components play a major role: loading, unloading, and cleaning. As we have discussed earlier, cleaning is an additional activity in tanker transport needed to prepare a tank for a future transport. Determining the servicing time durations is approached the same way as establishing the travel time durations. The sample distributions and the theoretical distributions for the durations of the loading and unloading trip components are depicted in figures 5-3 and 5-4.

From the graphical depiction of loading and unloading durations in figures 5-3 and 5-4, it is evident that the durations of these trip components contain significant fluctuations. This statement confirms the preliminary findings on page 95 that RTT has to cope with considerable fluctuations in trip execution. As the greater part of these fluctuations can not be foreseen, i.e., no clear relationship between the loading and unloading durations and characteristics of the loading or unloading location and/or the load exists, uncertainty is introduced into the trip execution process.

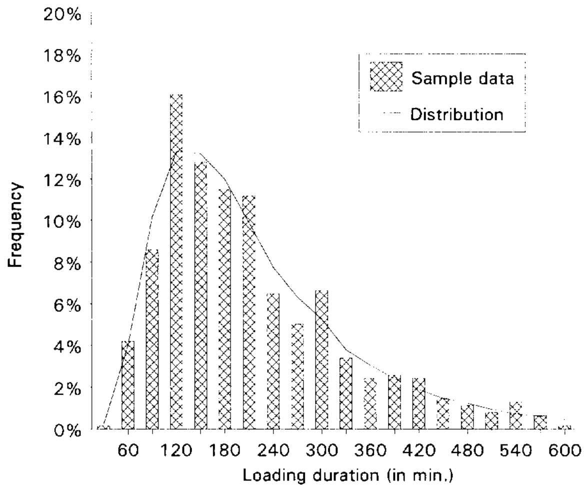

Figure 5-3 Distributions for duration of loading

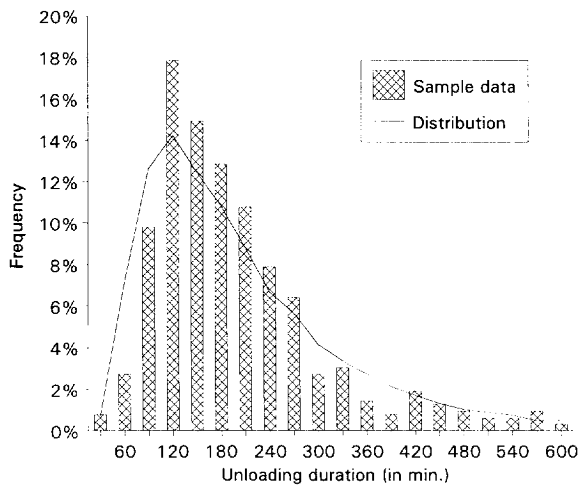

Figure 5-4 Distributions for durations of unloading

The probability distributions that are obtained from using the trip data analysis approach, are given in table 5-3.

	mean	s.d.	probability distribution
duration of loading (in min.)	210	143	LogN(210,143)
duration of unloading (in min.)	199	153	LogN(193,128)
duration of cleaning (in min.)	111	75	LogN(111,75)

Table 5-3 Probability distributions for servicing times

5.2.2 Modelling Fleet Management

In the previous section, we have argued that to obtain insight into the effects of using fleet management systems on the performance of trip execution, detailed modelling of a limited number of aspects of the fleet management process is required. When we look at the fleet management process on a global level, the kernel of this process is the driver assignment problem, as stated by Powell (1991). In the simulation model, we modelled the assignment of trips to transport combinations by incorporating an *assignment algorithm*, which simulates the composition of the trip plan by the dispatcher.

Transport orders

Transport orders contain an important part of the information needed to perform the fleet management tasks. This information may influence, directly or indirectly, the decision as to which transport combination the trip is going to be assigned.

In section 4.3, a service requirement has been defined as the requirement that the performance of an activity be initiated at a certain location after an earliest starting date and before a latest ending time (see definition 4-8). In tanker transport, service requirements can be set by the customer for the loading and unloading times of a transport order. Generally, a customer will require the haulier to load and unload the cargo on a specific date. The loading or unloading times of several transport orders are, however, subject to more rigid time restrictions. A customer can require the transport order to be loaded or unloaded before, on, or after a point of time during the day.

To model a transport order within the simulation model, the object class TRANSPORT ORDER presented in section 3.3.2, was refined and abstracted, yielding the following object class definition:

object class TRANSPORT ORDER
[**attributes**
Transport order identification
Loading region
Requested loading date
Requested loading time
Loading time restriction
Unloading region
Requested unloading date
Requested unloading time
Unloading time restriction
Product class of cargo
Volume of cargo
Presence of specific characteristic required?
Cleaning necessary?
]

Although the possible cleaning of a tanker depends on the product class of the cargo to be loaded next, to simplify the simulation model, an attribute is added to the object class definition indicating whether cleaning must be performed after execution of the transport order. The value of this boolean variable can be determined using several rules of thumb and several probability distributions that determine the probability of a tanker needing to be cleaned when carrying a certain product class.

For a period of eight weeks, actual transport order data were collected and prepared for use in the simulation model. We emphasize that only *real* data were used as input for the simulation model.

Trip assignment basics

The primary objective of assigning trips to transport combinations is to minimize the total distance driven, while meeting the time restrictions set by customers and meeting several other conditions, such as capacity restrictions, restrictions concerning the product class previously loaded, and restrictions with regard to the suitability of the transport combination to carry the load. A further objective of the assignment process is to involve as few transport combinations as possible in the trip execution process, given a fixed number of orders and trips.

The information required in the simulation model to perform the trip assignment process can be divided into two groups:

1. *Transport order data* of orders for which the requested loading date falls within one day from the current day. For a transport order, the time window the cargo should be loaded within was calculated from time restrictions and from some

general rules concerning opening times of locations, elicited from the dispatcher's knowledge.

2. *Trip execution status information* of transport combinations that are expected to become available within one day from the current day. Using the last trip execution status update received, an estimate of the finishing time of the current trip assignment was calculated using average driving, loading, and unloading durations, and taking into account the mandatory rest periods. A check was performed to see whether a transport combination will become unavailable at the expected finishing time due to maintenance, etc. Transport combinations that become available again within one day from the current day, after a period of unavailability, are included in the trip assignment process.

The descriptive conceptual model described in chapter 3 shows that the trip assignment process consists of preparing a provisional trip plan and making adjustments to this trip plan. To simulate the trip assignment process, this two-stage division was abandoned for two reasons. One, the first step is used to gain insight into the feasibility of the trip plan, providing an indication of a surplus or a deficit of orders or equipment in the trip plan. As the simulation model can be regarded as a "closed" system, i.e., the number of transport orders and transport combinations is fixed and therefore not subject to any (external) influences, obtaining insight into the feasibility of the trip plan is not applicable. Two, the *actual* trip assignment is only made in the second step of the assignment process, when the transport combination has finished its current trip assignment and is awaiting a new trip to be assigned.

In the simulation model, the trip assignment task is triggered by the arrival of a message from a transport combination requesting a new trip assignment. The trip assignment task as it takes place during simulation, was modelled using the task analysis technique (see also section 3.4). Figure 5-5 depicts the task HANDLE TRIP STATUS UPDATE MESSAGES.

If a transport combination is awaiting a new trip to be assigned, a new trip assignment is determined. It is possible that no adequate trip assignment for the transport combination can be found. In this case, assigning a trip to the transport combination will be postponed until an adequate trip assignment can be selected. If a trip can be assigned, the transport combination will be instructed to carry out the trip.

After a new trip is assigned or a trip status update is received, the trip execution status will be updated in the model, and the, adjusted, expected finishing time calculated, using average driving, loading, and unloading durations, taking into account the mandatory rest periods. In this manner, the discrepancy between actual and perceived trip execution status, mentioned in section 1.4, is incorporated in the model. Each time a trip status update is received, a calibration between the actual and the perceived trip execution status takes place, providing a starting-point for recalculating an estimate of the expected finishing time of the current trip assignment.

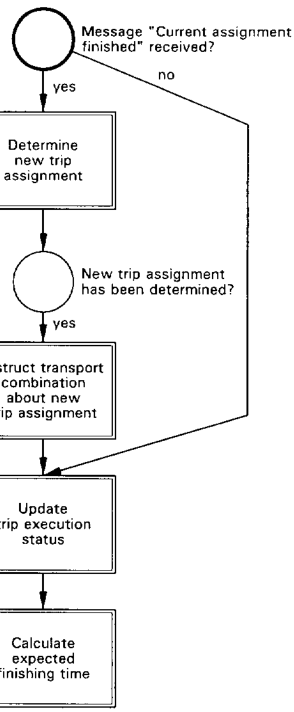

Figure 5-5 Task structure HANDLE TRIP STATUS UPDATE MESSAGES

As illustrated in figure 3-13, drivers contact the planning department to pass on trip status updates for a variety of events. For the RTT simulation model, these updates were refined and real data on the frequencies of passing on these updates were collected (Babeliowsky 1992, p. 62). These data are summarized in table 5-4; the type of trip status update, the event that relates to the trip status update, the time the update is sent, the probability that the trip status update is sent if this event occurs, and the accuracy of the point of time contained in the trip status update are presented.

After completion of an assignment, two different trip status update messages can be sent. If the driver must take a rest after finishing the trip, a trip status update message reporting the completion of the assignment only will be sent. If the driver does not have to take a rest, a trip status update requesting a new assignment will be sent. This update request will also be sent when the driver has taken his rest after completion of an assignment.

	Event	Moment of update	Probability	Accuracy
Finished	Completion of assignment	Immediately after finishing trip	100 %	Precise
Finished and request for new assignment	Completion of assignment	Immediately after finishing trip	100 %	Precise
Request new assignment	Combination becomes available	As soon as combination becomes available	100 %	Precise
Loaded	Combination is loaded	Immediately after loading	95 %	Precise
Unloaded	Combination is unloaded	Immediately after unloading	100 %	Precise
Regular	In the morning	8:30 a.m. - 11:00 a.m.	50 %	Precise
Delay	(Un)loading duration > 3.5 hr.	During first 3 hours of loading	65 %	± 30 min.
	(Un)loading duration > 5 hr.	During first 3 hours of loading	95 %	± 20 %
	Cleaning duration > 3.5 hr.	During first 2.25 hours of cleaning	90 %	± 20 %

Table 5-4 Overview of trip status update messages

Modelling trip assignment

Actual trip assignment is carried out by the task DETERMINE NEW TRIP ASSIGNMENT, shown in figure 5-5. Until now, we have not addressed the issue of selecting an appropriate assignment algorithm. To simulate the trip execution process, some form of simulation of the fleet management tasks of the dispatcher must be established. Before we turn to a discussion of how to simulate the assignment process, we restate that, in reality, assigning trips to transport combinations is a highly unstructured task, demanding the utmost of the dispatcher's intellect. Furthermore, a lot of implicit knowledge is involved in the assignment process, that we are unable to simulate in our model. Examples of this implicit knowledge are the preferences of drivers, the priority some customers may have over other customers in certain situations, etc.

In the course of the development of algorithms for solving planning problems in road transport, efforts have primarily been put into finding optimal solutions for the classical vehicle routing and scheduling problem using (Bodin *et al.* 1983). The results of this research, however, can not be used for the RTT simulation model. FTL transport, as is performed by RTT, faces an entirely different problem, as it involves assigning trips to transport combinations when the transport combinations become available after carrying out their previous assignment. This problem is referred to as the driver assignment problem (see section 3.1).

Assignment algorithms have been developed to solve assignment problems. An assignment algorithm tries to find a one-to-one assignment with some maximum total benefit, to be achieved at minimal cost. In general, assignment algorithms can be roughly categorized into *optimizing* and *non-optimizing* algorithms. Optimizing algorithms aim at providing an optimal solution for the assignment problem, often in terms of costs and benefits. Examples of optimizing algorithms are *back-tracking* algorithms (Bitner and Reingold 1975), the *Hungarian method* (Barr *et al.* 1977, Bertsekas 1981), and the *auction algorithm* (Bertsekas 1990).

Non-optimizing algorithms try to balance the costs to reach the solution - the computer time needed to execute the algorithm - and the quality of the solution - which will not be optimal. Examples of these algorithms are *heuristic search algorithms* (Rich 1983), the *set partitioning approach* (Fleuren 1988), and *local improvement* techniques (Powell 1991).

To implement the trip assignment problem in the simulation model, the use of a local improvement technique was chosen. The following motives underlie this decision:

- The way a local improvement technique delivers a trip assignment corresponds closely to the way dispatchers decide in practice upon a trip assignment.

- Local improvement techniques seem to deliver good quality solutions within a reasonable time (Powell 1991). The time needed to calculate a trip assignment is important in a simulation study, as it is a time-consuming process that must be carried out frequently.

- The use of a local improvement technique allows for both optimalization of the empty distances driven and satisfying the conditions concerning loading and unloading times, the avoidance of undesirable product classes to be loaded in a certain tank, etc. (It should be noted that all assignment algorithms are capable of incorporating these conditions.)

Figure 5-6 shows the task structure for determining the new trip assignment for a transport combination awaiting new instructions. The task starts with selecting the trips and transport combinations that are to be involved in the trip assignment process. Trips or transport combinations that deserve no consideration for assignment due to unavailability or geographical distance are filtered to minimize calculation time for the algorithm.

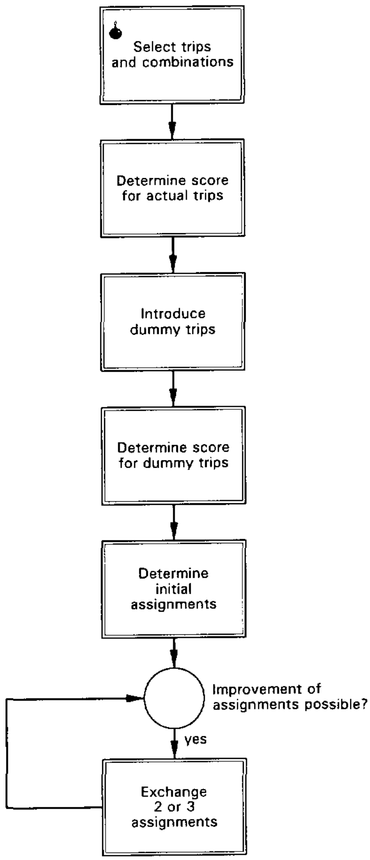

Figure 5-6 Task structure DETERMINE NEW TRIP ASSIGNMENT

Figure 5-7 presents the detailed task structure for the selection process of trips and transport combinations.

The points of departure for the selection process are the attributes of the transport combination awaiting a new assignment. Firstly, trips will be selected that satisfy the conditions demanded by the transport combination, concerning available capacity, the presence of a special characteristic, and the previously loaded product. Next, trips are selected within a certain range from the finishing region of the transport combination. Initially, this range will be about 200 kilometres. If the number of trips selected is too small or too large, the range is increased or decreased until a satisfactory number of trips is selected. The same procedure is followed for the selection of the transport combinations, where the initial selection will deliver a set of transport combinations that are expected to become available within one day from the current day.

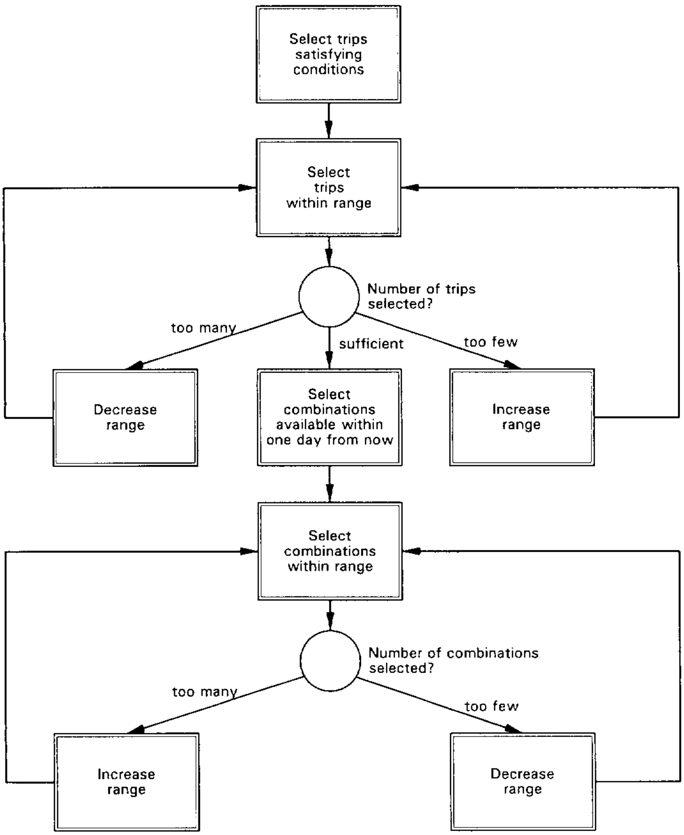

Figure 5-7 Task structure SELECT TRIPS AND COMBINATIONS

After the trips and transport combinations involved in the trip assignment process have been selected, a *penalty* score is calculated for each possible assignment of a trip to a transport combination, using the following penalty function:

$$P = \sum_{i=1}^{n} \gamma_i \cdot C_i \qquad (5\text{-}1)$$

where:
- P is the penalty calculated for the assignment of a certain trip to a certain transport combination;
- n is the number of penalty factors that constitute the penalty function;
- C_i is a penalty factor;
- γ_i is the weight factor for penalty factor C_i.

A *penalty factor* contributes to the overall penalty by being multiplied by a *weight factor* which determines the "importance" of the penalty factor. If a penalty factor has no contribution to the overall penalty, the value of the penalty factor will be zero. If the existence of a certain condition prevents the trip from being assigned to a transport combination, the corresponding penalty factor will be infinite.

The following penalty factors are included in the penalty function for the RTT simulation model:

- Capacity constraint;
- Suitability of previous product class loaded;
- Suitability of product class for transport combination;
- Presence of specific characteristic;
- Distance between finishing region and loading region;
- Punctuality with regard to expected loading time;
- Priority of trip.

The priority of a trip will increase if the trip should have been loaded the day before but still is unassigned.

The weight factors are expressed in terms of the distance to be driven from the finishing region to the loading region (Babeliowsky 1992, p. 211). For example, if two transport combinations can be assigned to the same trip but the transport combination nearest by would arrive two hours later than the requested loading time, the weight factor for the punctuality penalty factor will contain the number of kilometres that the dispatcher has to redirect the other transport combination to pick up the load on time. The weight factors for the penalty function were established by presenting the dispatchers at RTT hypothetical, but realistic examples such as the one above (see Cline *et al.* 1992).

The penalty factor for the expected loading time is illustrated as an example of a penalty factor and its associated values. The customer issuing a transport order to the haulier, is in the position to ask for a specific loading date and time. These customer demands can be translated into a time window, specifying the earliest loading time and the latest loading time. When the expected arrival time of the transport combination on the loading location falls within the time window, the penalty factor will be zero, if it does not, a penalty is attached, depending on whether the transport combination arrives earlier than the earliest loading time or later than the latest loading time. A function used in the RTT model that defines the penalty factor for the expected loading, is shown in figure 5-8.

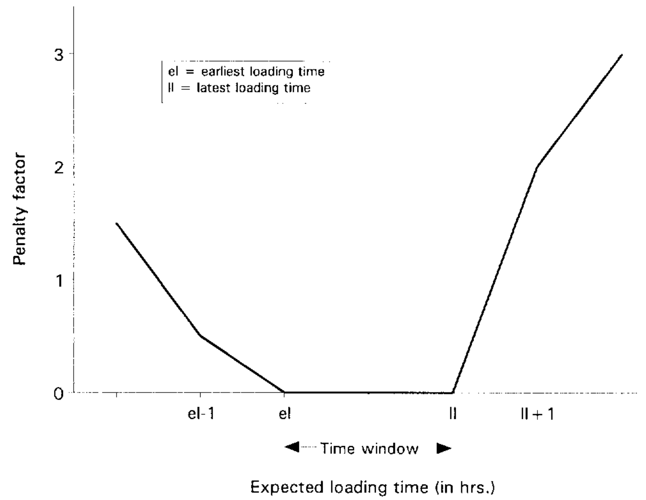

Figure 5-8 Penalty factor for the expected loading time

When execution of the task SELECT TRIPS AND COMBINATIONS results in more transport combinations selected than trips, the set of trips is expanded with *dummy loads* so that the numbers of trips and transport combinations are balanced (Powell 1991, p. 70). Introducing dummy loads offers the opportunity of not assigning a new trip to a transport combination, but having the transport combination idle for a while. This closely corresponds to reality, as future transport orders, currently unknown of, may be the best to assign to that particular transport combination, even when it has been idle. For the assignment of dummy loads that have been introduced to a transport combination, penalty scores will also be calculated using a different penalty function. The penalty for assignment of a dummy load to a transport combination depends on the type of equipment involved, the finishing region of the transport combination, and whether the transport combination is idle or not at the moment.

After all penalty scores are calculated, a local improvement algorithm is applied to find the best assignment for each trip. A local improvement algorithm is characterized by finding first an initial solution and then attempting to find better solutions. Improvements in the solution are called "local" as they typically involve only a few changes at a time. The algorithm embodied in the simulation model is a *k-interchange local improvement* algorithm (Lin and Kernighan 1973, Psaraftis 1983). In one local improvement iteration, k assignments are interchanged and the total penalty score over all assignments is recalculated. The algorithm we have applied in our simulation model uses the values $k=2$ and $k=3$. Firstly, an initial assignment is made by assigning the trip with the lowest penalty score that has not been assigned as yet to another transport combination. Next, a 2-interchange procedure and a 3-interchange procedure are performed to find the solution with the lowest overall penalty score. It should be stressed that this is a sub-optimal solution due to the heuristic nature of the algorithm applied. The choice for $k=2$ and $k=3$ is suggested by the fact that the $k=4$ case performs only marginally better than the $k=3$ case and will become computationally more expensive than the $k=3$ case (Psaraftis 1988, p. 235). For a comprehensive description of the implementation of the k-interchange local improvement algorithm in the RTT simulation model, see Blik *et al.* (1993).

5.2.3 Implementation of Simulation Model

A simulation model for RTT was specified in the previous two sections. The next step in our simulation study is to choose a simulation language. Neelamkavil (1987) gives a number of general requirements a simulation language should meet. We would like to highlight the following requirements for the simulation of the fleet management and trip execution processes at RTT (Babeliowsky 1992, pp. 79-80):

- The input data can be incorporated into the simulation model easily.

- Modifications in the trip execution model or the input data can be incorporated into the model without much effort.

- The simulation language allows for efficient implementation of the assignment algorithm.

- Statistical information needs to be collected during the simulation run and this information must be presented in a surveyable way after the run.

- The simulation language should have facilities for animating the simulation, allowing for validation by the dispatchers (Wierda 1991).

Based on the requirements mentioned above, we chose to use SIMAN/CINEMA IV™ to implement the transport process. In the SIMAN language, a distinction is made between a *model frame* and an *experimental frame*. The model frame contains the structural model of the system being modelled, whereas the experimental frame contains the input data and the output specifications (Hoover and Perry 1989, Pegden *et al.* 1990).

The third-generation language Microsoft C™ was selected (Microsoft 1991) to implement the assignment algorithm. This programming language allows for efficient and flexible implementation of the assignment algorithm and can be interfaced to the SIMAN language.

Using the CINEMA package, animation layouts were designed to allow observation of the simulation runs. These animation layouts offer the possibility of displaying the objects currently present and the effects of changes on attributes of these objects in a dynamic manner, while the simulation model is running. The animation feature of the CINEMA package was used to verify and validate the structure of the simulation model. Verification and validation of the model are described in section 5.3.

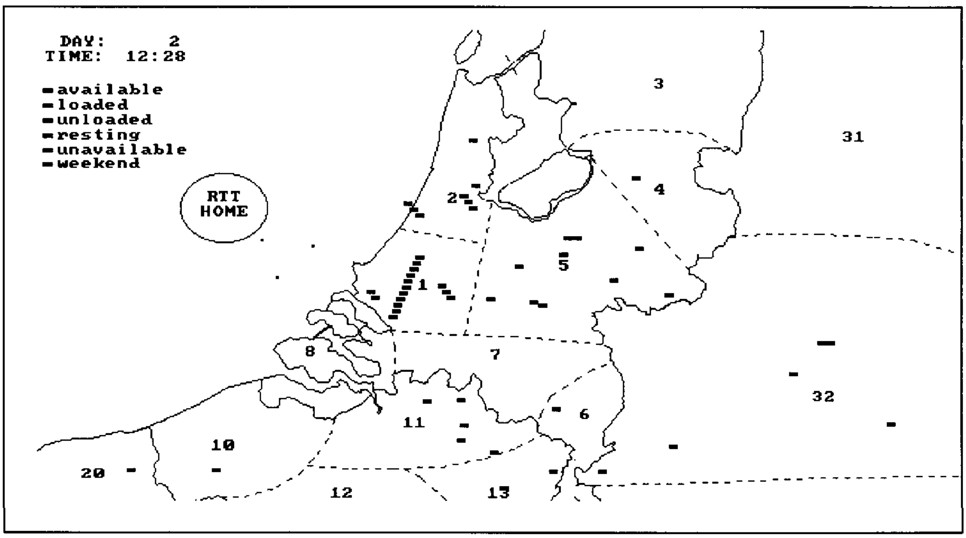

Figure 5-9 Animation view of the Netherlands and surrounding countries

The trip execution process is visualized using five maps of parts of Europe, on which the current location and the status of the transport combinations are visible. Figures 5-9 and 5-10 show two examples of the animation layouts and represent part of Europe. (In the actual animation views, colours are used to denote the geographical characteristics and the status of the transport combinations.)

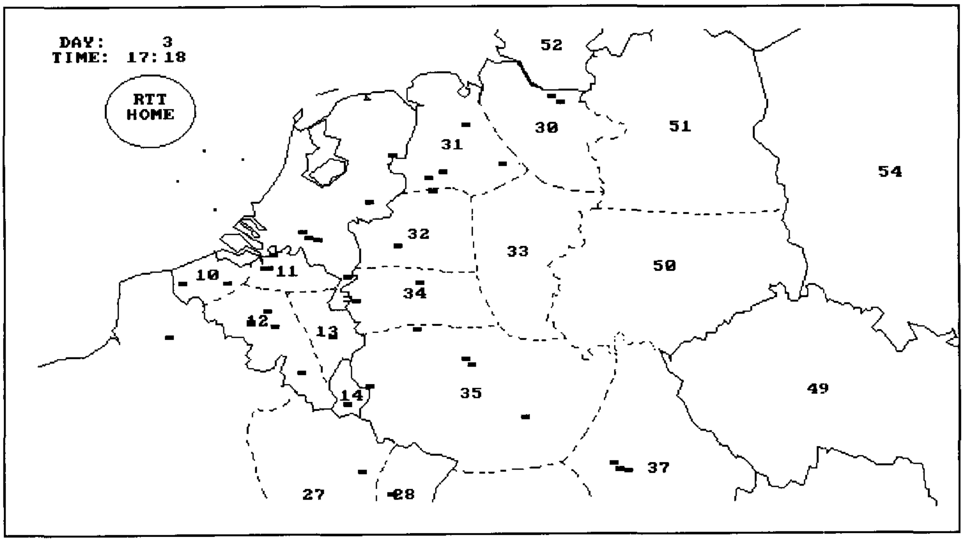

Figure 5-10 Animation view of the western part of Europe

DAY: 4
TIME:11:12

ACTUAL PROGRESSION

TRUCK	ASSIGN-MENT	STATUS	CURRENT AREA	STARTTIME OF:			TOTAL KILOMETERS	
4550	166	to unloading	11	LOADING:	4	7.00	EMPTY:	177
				UNLOADING:	0	.00	FILLED:	161
				CLEANING:	0	.00	DIRTY:	0
4551	133	to loading	11	LOADING:	0	.00	EMPTY:	1049
				UNLOADING:	0	.00	FILLED:	0
				CLEANING:	0	.00	DIRTY:	0
4552	147	cleaning	2	LOADING:	3	15.21	EMPTY:	273
				UNLOADING:	4	7.00	FILLED:	75
				CLEANING:	4	9.43	DIRTY:	35
4553	117	to cleaning	7	LOADING:	3	8.16	EMPTY:	423
				UNLOADING:	4	7.00	FILLED:	35
				CLEANING:	0	.00	DIRTY:	35
4554	102	unloading	6	LOADING:	3	7.00	EMPTY:	350
				UNLOADING:	4	7.00	FILLED:	339
				CLEANING:	0	.00	DIRTY:	0

Figure 5-11 View of actual trip execution status

On the maps, the coast-lines and frontiers are shown as solid lines, the dashed lines indicate the region boundaries. The numbers placed near the centre of a region indicate the number for that region, as it is used in the simulation model. The small rectangles depict transport combinations. The "RTT home" ellipse represents the planning department of RTT, this receives trip execution status updates from, and sends out driver instructions to transport combinations, indicated by small dots. (For the sake of clarity, the RTT home base has been placed at an arbitrary location that does not represent the actual location of RTT.)

A view on the actual progression of the trip execution process is shown in figure 5-11. For each transport combination, identification number, assigned trip, trip execution status, current region, and starting times of the three major trip components are displayed. The distances driven to the location where these trip components are actually carried out are shown in the last column.

DAY: 4
TIME: 11:12

EXPECTED PROGRESSION

TRUCK	ASSIGN-MENT	STATUS		END OF ASSIGNMENT	UNLOADING AREA	NEXT ASSIGNMENT	LOADING AREA
4550	166	to unloading	4 10.50	8 13.51	47	0	0
4551	133	to loading	3 7.10	5 18.05	35	0	0
4552	147	to cleaning	4 8.59	4 11.37	2	0	0
4553	117	to cleaning	4 10.54	4 13.32	7	0	0
4554	102	to unloading	3 15.31	4 14.28	6	0	0

Figure 5-12 View of the expected trip execution status

A view of the perceived and expected trip execution status is shown in figure 5-12. The last trip status update received for each transport combination is depicted by a combination symbol representing a certain status and the day and time of actual receipt. The expected finishing time of the assignment is included in the column next to it. If the transport combination has been (preliminary) assigned to a follow-on trip, as a result of the execution of the assignment algorithm for another transport combination, the identification number of this trip and the loading region are shown in the last two columns.

DAY: 4
TIME:11:12

EMPTY-FILLED-DIRTY

EMPTY KM'S	20.89 %
FILLED KM'S	60.56 %
DIRTY KM'S	10.55 %

# FINISHED ASSIGNMENTS:	103
AVG. FILLED KM'S:	375
AVG. TIME PER JOURNEY (min):	1876
EFFECTIVE VELOCITY (km/h):	12.01

AVG. TIME OF (min.)

LOADING	214
UNLOADING	195
CLEANING	90
BORDER (FULL)	59
BORDER (EMPTY)	37
RESTING	598

MESSAGES

TYPE 0	11
TYPE 1	92
TYPE 2	101
TYPE 3	149
TYPE 4	120
TYPE 5	16
TYPE 6	110

Figure 5-13 View of summarized output data

A number of statistics, based on data gathered during the simulation run, can be showed according to the view presented by figure 5-13.

For a detailed report on the implementation of the simulation model, see Blik *et al.* (1993).

5.3 Verification and Validation

Verification and validation of the simulation model must be performed to certify the correctness of the output of the simulation model. In other words, one should accomplish that the simulation model represents adequately the real-world system (Sol 1982).

Validation of the simulation model can be split into two activities: *structural validation* and *replicative validation*. Structural validation is intended to check whether the model behaviour is consistent with the behaviour of the real-world system. Replicative validation deals with certifying that the numerical output of the model is similar to the corresponding values in the real-world system (Sol 1982).

In the following sections, verification and validation of the RTT simulation model are discussed.

5.3.1 Verification

The verification process is aimed at ascertaining that the simulation model operates as intended. This activity is often designated *debugging*. To verify the model, we made frequent use of the animation views and the debugging tool supplied with the SIMAN package. Replacing frequency distributions by an average value, and thus eliminating stochasticity in the model, turned out to be a useful approach for detecting coding errors. This allowed a check to be performed as to whether the actual trip execution status corresponded to the expected - calculated - trip execution status.

5.3.2 Structural validation

The structural validation for the simulation model was initiated by performing a validation of the descriptive empirical model constructed for the RTT case. The object class definitions and the task structures were checked by showing them to the dispatchers. The correctness and completeness of the descriptive empirical model were tested using profound and searching questioning of the dispatchers. It appeared from the validation sessions that the task structures, after a short explanation of the task analysis primitives, provide an adequate "vehicle of communication," as the dispatchers proposed a large number of correct modifications to the task structures.

In the simulation model, a number of abstractions were made to obtain an employable representation of the - complex - real-world situation. Each abstraction made to the model was submitted to a thorough and critical judgment process (Babeliowsky 1992). For most abstractions, the consequences for the behaviour of the simulation model were very difficult to determine. Some abstractions applied can, however, be validated in a structural way.

The classifications of products and transport combinations can be validated using historical trip data. Almost 2400 trips carried out by RTT have been analyzed using the rules determined for the simulation model. This analysis resulted in the relaxation of some rules and in the introduction of large penalty scores in the penalty function of the assignment algorithm, allowing for a non-ideal assignment of a trip to a transport combination, but only at high cost to the penalty score.

Structural validation can be supported by performing a *sensitivity analysis*. By varying the values of the parameters of the simulation model and analysing the effects of these changes on the model's behaviour, a feeling for the uncertainty in the parameter values can be obtained (Pegden *et al.* 1990, p. 157). A limited sensitivity analysis of the parameters of the assignment algorithm is carried out, but due to the limited time available to carry out the simulation study and the long run time for one replication, an extensive analysis was omitted. (The run time for one replication of four weeks on an 80386DX/25MHz Personal Computer, equipped with a coprocessor, is about 7.5 hours.)

The *animation* feature included in the simulation model is a tool for validation we used often during the simulation study. Animation can be used to establish the structural validity of a simulation model by providing a view of the dynamic properties of the system being modelled (Bots *et al.* 1992, Dur 1992, Wierda 1991). To increase confidence in the model structure, the simulation and animation model was demonstrated to the dispatchers at the RTT planning department.

5.3.3 Replicative validation

Replicative validation ascertains the correctness of the simulation model's output. To obtain this output, a *treatment* of the simulation model must be made. A treatment consists of the following components (Ören and Zeigler 1979, Sol 1982):

- Specification of input data;
- Collection of input data;
- Initialization conditions;
- Run control conditions;
- Specification of output data.

The input data for our simulation model is specified in section 5.2. The tables, rules, and frequency distributions used as input for the simulation model, were validated by consulting the dispatchers, by performing χ^2 and Kolmogorov-Smirnov tests, and by graphic presentation of the data (Babeliowsky 1992, pp. 213-220).

A distinction should be made between *terminating* and *non-terminating* systems when determining the initialization conditions (Hoover and Perry 1989). A terminating system has a fixed initial state and the end of activities is marked by a certain event. The trip execution process at RTT is an ongoing process, where the drivers do indeed stop driving each night, but resume their activities the following day at the point where they left off, furthermore, at the week-end, not all transport combinations return to their home base. It is for these two reasons, that we regard the trip execution process as a non-terminating system. When simulating a non-terminating system, the initial state should be determined and the decision whether or not to employ a start-up time in the simulation must be taken.

The initial state for the simulation model was recovered easily, as the starting date of the simulation came after a period of vacation for most of the drivers. For the remaining drivers, the previous assignment and finishing regions were determined. The initial (un)availability for the transport combinations was determined also.

The start-up time is the time the model needs to overcome possible start-up effects (Wilson and Pritsker 1978). A general approach to determine the start-up time is to trace the value of an output variable while the simulation is running. Simultaneously, some parameters of the assignment algorithm, that influence the outcome of the experiments considerably, were adjusted. It appeared from the results of a number of test runs that the outcome of the simulation model is very sensitive to the values of two parameters: the difference between the maximum number of selected trips and the maximum number of selected transport combinations, and the weight factor for the penalty factor "expected loading time." After the execution of a number of additional test runs, the correct parameter adjustments were found. It could be concluded from the results of the test runs executed during this tuning process, that the values of the output variables do not vary significantly as simulation time proceeds and that the values of the output variables do not stabilize after a period of time. Hence, we concluded the start-up time of the simulation model is zero.

To determine the run length of a simulation model, a much applied rule of thumb is to take three times the length of the longest cycle in the system. For the RTT simulation model, this cycle length is one week as drivers, in general, return home at the weekend and start working again at the beginning of the following week. To be on the safe side, we choose a run length of four weeks.

Specification of the output data concludes the description of the treatment. As we are interested in the differences in effectiveness of the fleet management process before and after the introduction of mobile communications, output variables must be figured out that can be regarded as measures for effectiveness.

The following output variables were determined for the RTT simulation model:

- *Percentage of loaded kilometres*. The number of kilometres that are driven with a load establishes a measure for the efficiency of the trip execution process, and hence for the effectiveness of the fleet management process, in contrast to the "deadheaded" kilometres.

- *Punctuality of loading and unloading*. Punctuality is defined as the percentage of trips where the transport combinations arrive at the loading or unloading location on or before the requested date. If a time constraint has been set by the customer, a trip will be considered to be punctual if the transport combination arrives no later than 15 minutes after the requested time.

- *Number of orders not assigned.* The model simulates actual trip executions, carried out at RTT during a certain period. Due to abstractions in the simulation model, it is possible that trips were not assigned during the simulation, since trips were removed from the set of trips that still have to be executed, if not assigned after an elapse of two days from the requested loading date. Thus, the number of trips not assigned can be regarded as a measure of the effectiveness of the fleet management process.

- *Effective speed.* The effective speed is the total number of loaded kilometres divided by the overall time necessary to carry out the transports, including the rest time of the drivers.

- *Number of inactive combinations.* The number of inactive transport combinations is the average number of combinations not to a trip. As a fixed number of transport orders must be executed for the simulation model, the number of inactive transport combinations presents a measure of the effectiveness of the trip assignment process.

Now the output variables have been determined, the number of replications required to obtain meaningful results from the simulation model's output, must be calculated. Replications are runs of the simulation model under the same treatment, each with unique initial random stream values, so that the results of each replication can be viewed as independent. The number of replications was determined by the following procedure (Dur 1992, Kleijnen and Van Groenendaal 1992, Van Soest 1985):

1. Establish an acceptable level of risk.

2. Draw a sample of N_0 observations of the output variables by performing N_0 replications.

3. Calculate the sample variance s^2 for each output variable.

4. Establish an acceptable width δ of the (1-α) confidence interval for each output variable.

5. Determine the required number of replications N using:

$$N \geq \frac{4\, t^2_{\frac{1}{2}\alpha}(N_0-1)\, s^2}{\delta^2} \qquad (5\text{-}2)$$

where:

- $t_{\frac{1}{2}\alpha}(N_0-1)$ is the appropriate value taken from a table of the *t* distribution.

The number of replications to be executed, depends for the greater part on the confidence intervals that are defined for the output variables. It is very common in simulation studies to select $\alpha=0.05$ or $\alpha=0.10$ for the level of risk, however, because of the considerable run time for one replication and the level of abstraction in the simulation model, the value of $\alpha=0.10$ is preferred.

For the value of the width δ of the $(1-\alpha)$ confidence interval for each output variable, we took one third of the interval between the lowest and highest value in the sample of N_0 replications (Van Soest 1985). This value also has been used several times in actual simulation studies (Dur 1992, Motshagen 1991).

	obs	min	max	δ	stand. dev.	replications required
percentage of loaded kilometres	8	65.7	66.3	0.20	0.227	18
punctuality loading (time constraint)	8	38.7	55.4	5.6	4.81	11
punctuality unloading (time constraint)	8	44.4	63.0	6.2	7.23	20
punctuality loading	8	57.4	65.9	2.8	3.10	17
punctuality unloading	8	56.0	64.2	2.7	2.94	17
number of trips not assigned	8	1	8	2.33	2.13	12
effective speed	8	11.72	11.81	0.03	0.030	15
number of inactive combinations	8	1.97	2.50	0.18	0.183	16
$\alpha = 0.10$ $t_{0.05}(7) = 1.895$						Max: 20

Table 5-5 Calculation of the number of replications required

The results of applying the procedure described above to the value of pilot replications $N_0=8$ are presented in table 5-5. This table lists the number of observations, the minimum and maximum values found in the set of pilot replications, the interval width δ, the standard deviation, and the number of replications required for each output variable. From the results in table 5-5, it is clear that 12 additional replications must be performed.

	mean	s.d.	90 % confidence interval
percentage of loaded kilometres	66.0 %	0.206	[65.9, 66.1]
punctuality loading (time constraint)	47.2 %	5.02	[45.3, 49.2]
punctuality unloading (time constraint)	50.5 %	6.30	[48.0, 52.9]
punctuality loading	61.0 %	3.77	[59.5, 62.4]
punctuality unloading	61.5 %	3.10	[60.3, 62.6]
number of trips not assigned	4.25	2.57	[3.26, 5.24]
effective speed	11.74 km/h	0.042	[11.73, 11.76]
number of inactive combinations	2.31	0.184	[2.24, 2.39]

Table 5-6 Results derived from the descriptive simulation model

The sample mean, the standard deviation, and the confidence interval of each output variable are shown in table 5-6.

A replicative validation requires the values of the output variables to be compared with the corresponding values as they emerge from the actual trip execution process. For the percentage of loaded kilometres, actual data were available from three different sources. When we compared the mean percentage of the loaded kilometres from these sources, which is 64.8 percent with a standard deviation of 3.5, we concluded that the model output provided a good reflection of the value in reality.

Data for a specific customer of RTT were available to validate the punctuality of the loading and unloading times. About 68 percent of the transport combinations carrying out trips for this customer arrived on time at the loading location. Hence, the punctuality of loading times is significantly better in reality than in the simulation model. Several reasons can be pointed out for this difference:

- In reality, dependencies exist between fluctuations in trip component durations and the properties of a certain trip component. For example, at a certain loading location the loading process will always last longer than the average loading process. As a consequence, dispatchers are able to predict the expected trip component durations more accurately than the model can. These dependencies were not modelled because it required a lot of additional, often implicit, knowledge to be incorporated in the model.

- The rules concerning loading and unloading times are implemented rather rigidly in the simulation model. For example, if a time constraint is imposed on the loading time and the transport combination arrives one hour late, in the model the combination must wait until the following morning before loading can be started. In reality, arriving late will not always result in a delay.

- Drivers are able to adapt themselves to certain situations, whereas the model lacks this capability. If drivers expect to arrive late, they will drive faster or take less rest if possible, thus arriving on time.

Pilot runs that omitted stochasticity in the model yielded results, comparable to the values in reality. As the main purpose of this simulation study was to compare the output variables before and after the introduction of mobile communications, and because of technical limitations of the simulation package, no modifications for improving punctuality of the loading and unloading processes were made to the descriptive simulation model.

For the other output variables, no actual data were available to perform a replicative validation. The validation of these output variables was performed by *face validity* (Pegden *et al.* 1990, p. 157). Face validity was achieved by having the dispatchers, who are very knowledgable about the organization being modelled, judge whether the outcomes of the simulation model appeared to be reasonable. The number of inactive combinations comprised 2.5 percent of the total number of available transport combinations. The number of trips that can not be assigned to a transport combination was only 0.4 percent of the total number of trips assigned during the simulation runs. The RTT dispatchers consider the values of the output variables, including the value for the effective speed, to be realistic.

The trip status updates sent by the driver were recorded to enable analysis of the communication patterns between dispatchers and drivers. The analysis of the communication pattern was also used to increase confidence in the simulation and therefore contributed to the validation and verification of the simulation model. It appeared that the communication pattern established from the simulation model output seemed to show a good correspondence to the actual communication pattern.

Figure 5-14 shows the number of updates received during simulation time for each status update type from table 5-4. The remarkable number of requests for a new assignment on day 1, a Monday, was caused by the large quantity of transport combinations that became available again after a vacation period.

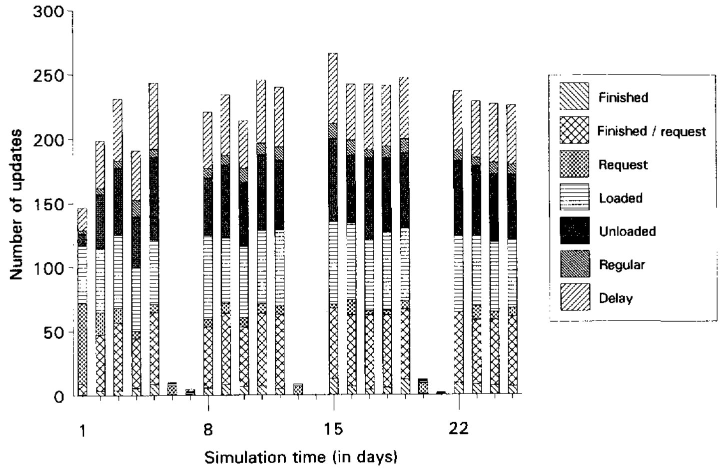

Figure 5-14 Trip status updates sent by transport combinations (per day)

An overview of the incoming updates during the course of the day is depicted in figure 5-15. The average number of updates received over all working-days in the simulation (from Monday through Friday) is shown for each interval of one hour.

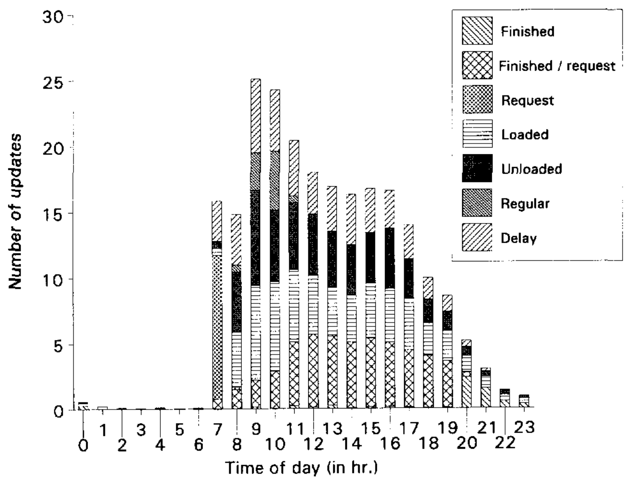

Figure 5-15 Average number of trip status updates (per hour)

From the figures 5-14 and 5-15, it can be concluded that about forty reports of delays are received during the day, and that delay reports also arrive late in the afternoon and early in the evening. As a delay report may result in an adjustment of the trip plan, the dispatchers must work late to prepare a final trip plan. This statement is confirmed by the fact that a number of messages reporting a finished assignment and requesting a new trip to be assigned, arrive at the same time of day. Furthermore, the large number of updates requesting a new trip to be assigned, that arrived early in the morning was, in reality, dealt with the day before. As the dispatchers are not present in the planning department when these updates arrive, new trips are assigned to the drivers when they report the end of their current assignment but still have to take their rest. This way of working has no further consequences on the trip execution process.

5.4 Experiments and Results

The validation of the RTT simulation model is described in the previous section. Whilst we regard this model as valid, several motivations have been put forward to confirm the validity of the model, the model can be used to evaluate alternatives for the existing organization. The results of the descriptive simulation model thus serve as a *yard stick* to which the results of the prescriptive model system can be compared (Sol 1982).

The investigation and evaluation of each alternative will be referred to as an *experiment*. The experiments devised for the RTT model were based on the layout for the fleet management system developed in chapter 4. This FMS layout incorporates the use of mobile communications by having the drivers send preprogrammed messages concerning current trip execution status. Positions can be reported without the intervention of the driver, if the mobile communication system used in the FMS has an automatic vehicle location (AVL) capability. As the trucks are equipped with a mobile communication system, drivers have the opportunity to send trip status updates at each point of time. This feature of a mobile communication system is utilized to introduce more frequent status and position updates in the communications to the planning department, see figure 4-1 and figure 4-2. The FMS applies the *management-by-exception* principle to handle the incoming flow of frequent status updates, enabling an increase in sending trip status updates without overloading the dispatcher with information, and allowing for automatic and centralized registration of trip status information. Centralized registration of trip status information facilitates the provision of more actual and accurate information to the customer.

The properties of the FMS described above were used to devise the experiments for the (prescriptive) simulation models. These properties served as a guideline when making adjustments to the descriptive simulation model.

An increase in loaded kilometres for the prescriptive simulation model is not very likely, as the set of orders is fixed, but an increase in the punctuality of arrivals at loading and unloading locations is expected. If transport combinations arrive on time more often, waiting times will diminish, finally resulting in a higher effective speed. Moreover, the improvements achieved can be expected to give greater customer satisfaction and yield a reduction in necessary transport capacity.

Four experiments are described in the next sections. Section 5.4.1 presents the experiment in which more frequent trip status updates were introduced. In section 5.4.2, this experiment is extended by sending pre-arrival notices to the loading and unloading locations to reduce the time taken to load and unload. Section 5.4.3 describes the case where customers impose more time constraints on the transport orders. The results of executing the simulation model with an additional set of trips are discussed in section 5.4.4.

5.4.1 Sending Frequent Trip Status Updates

Sending trip status updates more frequently has consequences for the structure of the simulation model. In the descriptive model, no trip status updates were sent while the transport combinations are on the road, unless a frequent trip status update needs to be sent. These are only sent in the morning with a probability of 50 percent, see table 5-4. In the "new situation," trip status updates containing the current position, in kilometres from the origin location to the destination location, status and time are sent each hour the transport combination is on the road. The status update frequency of one hour was chosen for several reasons. One, the frequency selected was significant higher than the frequency for sending frequent updates in the descriptive model. Two, the frequency of one hour was suggested by the dispatchers, who have experience of frequent position updates as they were involved in the mobile satellite communications trial, see section 2.6. Three, the currently available mobile communication systems offer the possibilities of sending position reports at the selected frequency as part of the standard service (Jacobs *et al.* 1991).

As the driver has a mobile communication terminal within reach, trip status updates can also be sent more frequently from loading and unloading locations. In contrast to the current situation, where the driver is dependent on the availability of a telephone or the readiness of an employee at the location to let the driver use a telephone; with mobile communications, drivers are able to report an estimate of the expected finishing time of loading or unloading in an early stage. In the prescriptive model, this is modelled by sending a trip status update containing an expected finishing time from a loading, unloading, or a cleaning location within the first hour of the process concerned, unless the time taken will be less than 1.5 hours. These trip status updates were sent in 95 percent of the cases with an accuracy of 20 percent. The properties of the other trip status updates from table 5-4 remain unchanged.

Table 5-7 summarizes the results of introducing more frequent trip status updates. The table shows the mean and standard deviation for all output variables for the current situation and the experiment performed. To compare the outcomes of the two simulation models, a *t*-test is performed (Kleijnen 1992, Neter *et al.* 1988), the *t*-value and an indication of significance for the confidence levels $\alpha=0.05$ and $\alpha=0.10$ are also given in table 5-7.

From the results, we can conclude that the differences from the current situation are limited. The percentage of loaded kilometres, the punctuality, and the number of inactive combinations do not improve significantly. (An increase for the percentage of punctual unloaded trips with time constraints is, however, established but only for 2.8 percent of all trips, time constraints are imposed on the unloading of trips.) The number of trips not assigned during the simulation decreases significantly. As this output variable only exist in the simulation model (see page 122), it is hard to conclude how this outcome will translate to reality, however, as the number of trips that are not assigned represents a measure of the effectiveness of the trip assignment task, one may conclude that effectiveness of the trip assignment task will increase in reality. This statement is supported by the significant increase of the effective speed. Although this increase is small - about 0.34 percent - it indicates that the driver's time efficiency will improve.

	current situation (n = 20)		status updates more frequently (n = 20)			significance level	
	mean	s.d.	mean	s.d.	$\lvert t \rvert$	0.05	0.10
loaded kilometres	66.0	0.206	66.0	0.447	0.091	n.s.	n.s.
loading (constraint)	47.2	5.02	48.5	6.77	0.65	n.s.	n.s.
unloading (constraint)	50.5	6.30	57.5	7.39	3.22		
loading	61.0	3.77	61.7	4.86	0.55	n.s.	n.s.
unloading	61.5	3.10	62.5	4.69	0.87	n.s.	n.s.
trips not assigned	4.25	2.57	2.40	2.26	2.42		
effective speed	11.74	0.042	11.78	0.048	2.80		
inactive combinations	2.31	0.184	2.33	0.188	0.32	n.s.	n.s.

$t_{0.025}(38) = 2.024$ $t_{0.05}(38) = 1.686$ n.s.: not significant

Table 5-7 Evaluation of sending trip status updates more frequently

The average number of trip status updates that arrived during the day is depicted in figure 5-16. Frequent trip status updates have been omitted from this figure as their number increased from an average of 8.3 updates per day to 757 per day! When the distribution of the incoming trip status updates in the new situation was compared to the current situation, the number of updates reporting on the expected finishing time of loading, unloading, and the cleaning processes arriving rather early in the new situation attracts attention. As the dispatchers arrive between 8:00 a.m. and 9:00 a.m. at the planning department, the Fleet Management System needs to be able to handle these trip status updates in an adequate way.

A supplementary experiment was carried out following the method described in this section to increase the frequency of status and location reports to 15 minutes. No significant difference from the situation in which updates are reported each hour can be established for all of the output variables.

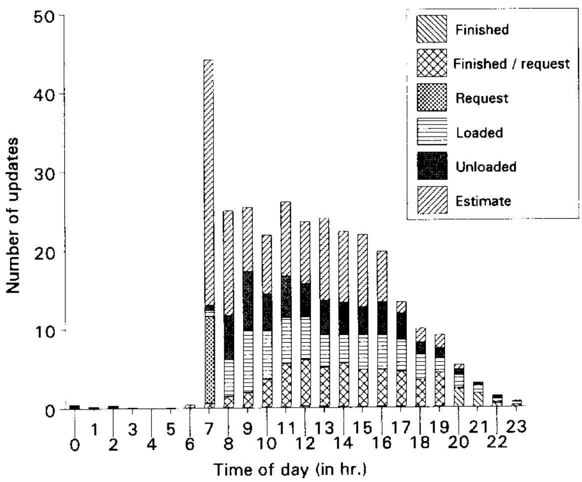

Figure 5-16 Average number of trip status updates when increasing frequency

5.4.2 *Using Pre-arrival Notices*

The functionality of the FMS allows the provision of adequate information to the customer, as shown in chapter 4. Given that the transport combinations send a trip status updates each hour, it is possible to inform accurately the loading, unloading, or cleaning location of the *expected time of arrival* (ETA) at the location concerned, a short time ahead of arrival. Although announcing the arrival at the location is also possible and sometimes even requested by the customer, in the current situation using the scheduled times from the trip plan, this is not as accurate as the alternative described in this section. Announcing an ETA of the transport combination or a delay has several major advantages:

- Activities carried out at the location, such as preparing forms, can be performed before the transportation combination arrives.

- If the waiting time at a cleaning location is expected to be too long, the dispatcher can consider having the transport combination cleaned elsewhere, this is only possible when a mobile communication system is available.

- Possibly, arrangements can be made with the management at the locations for transport combinations that are announced properly to have priority over others.

- In the case of a faulty trip or order, i.e., a mistake is made by the customer issuing an order or by the dispatcher instructing a driver, the fault can be detected earlier so the driver will drive fewer empty-headed kilometres or has to wait a shorter time at the location before he or she can continue his or her activities.

- In the case where the location of the load to be picked up or to be delivered is unknown, communication can take place between the location, the customer, and the dispatcher to solve the problem before the transport combination arrives at the location. This will result in less waiting time for the driver.

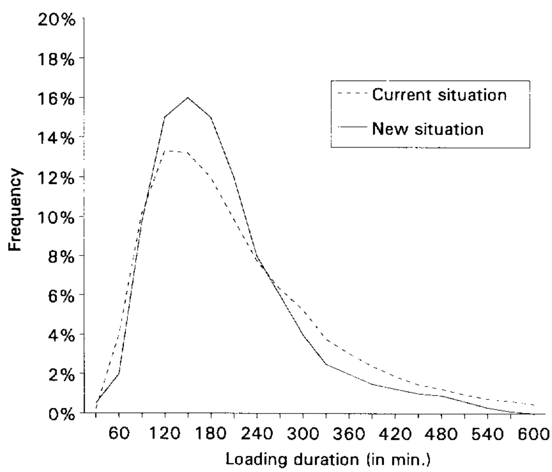

Figure 5-17 Frequency distributions of loading duration for current and new situation

These advantages will result in the average loading and unloading durations and the variation of these times to diminish. Cleaning durations have been left out of our analysis. As we do not have actual data on the improvements that can probably can be achieved in the loading and unloading durations, we must estimate the effects of using pre-arrival notices. As a guideline, we consider that durations of six hours or more will no longer occur. If these durations are left out of the original sample distribution of the loading and unloading durations, which count for up to 8.4 percent of the total sample, we obtain a new sample for which probability distributions can be determined. The average of the new sample for the loading durations is reduced by 14.5 percent and the standard deviation is decreased by 44.8 percent. The probability distributions of the loading durations for the current and the new situation are shown in figure 5-17. As the modifications to the probability distribution of unloading durations are similar, they are not explained explicitly.

To relieve the dispatcher's task concerning the passing on of pre-arrival notices, *electronic data interchange* (EDI) can be used. Pre-arrival notices will be generated automatically and in a structured way, sent to the customer's, the shipper's, or the consignee's computer, this will also save time for these organizations. If these parties are not able to receive EDI messages, automatically generated fax messages can be forwarded (Streng and Sol 1992).

	current situation (n = 20)		using pre-arrival notices (n = 20)			significance level	
	mean	s.d.	mean	s.d.	| t |	0.05	0.10
loaded kilometres	66.0	0.206	65.0	0.192	16.1	all significant	all significant
loading (constraint)	47.2	5.02	69.6	3.79	15.9		
unloading (constraint)	50.5	6.30	67.2	6.56	8.21		
loading	61.0	3.77	77.2	2.23	16.5		
unloading	61.5	3.10	76.1	1.85	18.2		
trips not assigned	4.25	2.57	0.85	0.875	5.60		
effective speed	11.74	0.042	12.02	0.050	18.9		
inactive combinations	2.31	0.184	2.64	0.214	5.09		

$t_{0.025}(38) = 2.024$ $t_{0.05}(38) = 1.686$

Table 5-8 Evaluation of effects when using pre-arrival notices

From the results given in table 5-8, the conclusion can be drawn that introducing pre-arrival notices, will yield in a substantial improvement of the trip execution process, provided that the reductions in loading and unloading durations can actually be achieved. Punctuality of arrival times at (un)loading locations improves significantly as uncertainty in the trip execution process decreases. Further, the effective speed increases because of the shorter loading and unloading durations and the number of transport combinations used decreases. The decrease of loaded kilometres is an exception to the improvements in the trip execution process. As more time is available for the execution of trips and punctuality of trips counts heavily in the penalty score, the assignment algorithm tends to fulfil the punctuality constraints at the expense of kilometres driven.

5.4.3 Increased Loading and Unloading Time Restrictions

The previous two experiments were carried out using the set of transport orders that were determined while building the descriptive model system. To recall, this set represents the real trips performed at RTT during the investigation period.

As customers are tending to increase loading and unloading time restrictions, we have called attention to this trend in chapter 1, an additional experiment was performed to investigate the effects of an increase in loading and unloading time restrictions. This experiment tried to answer a "what-if" question for the case where time restrictions are increased.

To model the more restricted loading and unloading times, an analysis of the current set of transport orders was made to determine the frequency of time constraints. The frequency of loading and unloading time constraints was 21.7 percent and 2.8 percent. In this experiment we roughly redoubled the percentage of time-constrained orders, requiring an exact loading or unloading time. The new frequencies were found to be 37.8 percent and 6.9 percent.

Pilot runs were again performed on the adjusted descriptive model system to determine the number of replications required to obtain significant results, this was calculated to be 20. The results of running the pilot and additional runs are summarized in table 5-9. From these results, it is clear that the punctuality of loading and unloading processes decreases significantly when compared to the original descriptive model system, as is expected. No differences in the other output variables can be seen. To examine the possible effects of using mobile communications in a situation with increased loading and unloading time restrictions, an experiment with the more frequent trip status updates, described in section 5.4.1, was performed. The results of the simulations for the new situation are given in table 5-10.

	mean	s.d.	90 % confidence interval
percentage of loaded kilometres	66.2 %	0.293	[66.1, 66.3]
punctuality loading (time constraints)	39.7 %	2.82	[38.6, 40.8]
punctuality unloading (time constraints)	49.3 %	6.23	[46.9, 51.7]
punctuality loading	56.2 %	4.88	[54.4, 58.1]
punctuality unloading	58.3 %	2.97	[57.2, 59.5]
number of trips not assigned	3.45	2.82	[2.36, 4.54]
effective velocity	11.75 km/h	0.052	[11.73, 11.77]
number of inactive combinations	2.26	0.137	[2.20, 2.31]

Table 5-9 Results for the model with increased loading and unloading restrictions

Evidently, using more frequent status updates has no effect on the performance of the trip execution process when increased loading and unloading time restrictions are applied. It appeared that the stochasticity in this process cannot be dealt with by providing more accurate and actual trip status information to the trip assignment process.

	current situation (n = 20)		status updates each hour (n = 20)			significance level	
	mean	s.d.	mean	s.d.	| t |	0.05	0.10
loaded kilometres	66.2	0.293	66.1	0.366	0.72	n.s.	n.s.
loading (constraint)	39.7	2.82	39.7	3.32	0	n.s.	n.s.
unloading (constraint)	49.3	6.23	50.7	5.40	0.76	n.s.	n.s.
loading	56.2	4.88	56.6	4.22	0.26	n.s.	n.s.
unloading	58.3	2.97	58.9	3.53	0.59	n.s.	n.s.
trips not assigned	3.45	2.82	3.30	2.90	0.17	n.s.	n.s.
effective speed	11.75	0.052	11.75	0.052	0.40	n.s.	n.s.
inactive combinations	2.26	0.137	2.25	0.226	0.14	n.s.	n.s.

$t_{0.025}(38) = 2.024$ $t_{0.05}(38) = 1.686$ n.s.: not significant

Table 5-10 Evaluation of effects for increased time restrictions

5.4.4 Increased Amount of Transport Orders

Another "what-if" experiment was performed to determine the effect of increasing the amount of transport orders. For the current situation, the simulation was based on a fixed set of orders, in reality each order attuned to each other by the dispatchers to obtain, at as low as possible cost, a feasible trip plan. Consequently, the elimination of surpluses or deficits of transport orders or equipment was not incorporated into the simulation model.

The question answered in this section is what are the effects of using mobile communications when more transport orders are included in the simulation model, and the number of available transport combinations is kept constant. As a matter of course, doing this will mean that the total available transport capacity will not suffice to carry out all transport orders. Although this is absolutely inadmissible in reality, for the simulation model it provided a measure for the effectiveness of the trip assignment process in the new situation.

To model the increased amount of transport orders to be carried out, an analysis was made of the current set of orders. Probability distributions were determined for the product classes, the loading regions, the unloading regions, and time restrictions. Using these distributions, a random combination of these attributes was drawn. Next, from the overall set of orders, transport orders were selected that match this combination. From the reduced set of orders, one transport order was selected at random of which all attributes, except for the loading day, are copied to the transport order being drafted. The loading day was determined using a random distribution, but was restricted by the maximum weekly number of transport orders to be added to the simulation model, i.e., 15 or 16, depending on the number of orders used in the model for that week. In total, 62 transport orders were added to the model using the procedure described above, an increase of 5.0 percent over the original set of orders. This percentage was chosen more or less arbitrarily.

Pilot runs were performed for the adjusted descriptive model system to determine the number of replications required to obtain useful results. The total number of replications required was calculated to be 18. The results of the experiment adding additional orders to the simulation model are shown in table 5-11.

As a consequence of the increased number of trips, the assignment algorithm has an increased number of trips available to choose a trip to be assigned to a transport combination, yielding in fewer empty-headed kilometres to be driven. Clearly, the percentage of loaded kilometres has increased significantly as has the effective speed. The number of inactive combinations decreased because more opportunities are available to assign a trip to an inactive combination. Punctuality of loading and unloading decreased as the number of trips given priority increased due to the fact that they were not yet assigned on the requested date. The difference between the number of orders added to the simulation model and the number of trips not assigned during the simulation is about 20, which means that the assignment algorithm managed to assign these trips though they are not in reality included in the set of orders. Two reasons exist to explain this behaviour. One, as we have already mentioned, more combinations were brought into action. Two, the trip assignment algorithm assigns fewer inconvenient trips to transport combinations, i.e., less trips were assigned for which an unsuitable future assignment needs to be selected.

	mean	s.d.	90 % confidence interval
percentage of loaded kilometres	67.3 %	0.319	[67.1, 67.4]
punctuality loading (constraint)	28.7 %	2.74	[27.6, 29.9]
punctuality unloading (constraint)	45.3 %	9.17	[41.6, 49.0]
punctuality loading	44.9 %	2.38	[43.9, 45.9]
punctuality unloading	45.8 %	2.35	[44.8, 46.7]
number of trips not assigned	39.6	9.57	[35.7, 43.5]
effective speed	11.79 km/h	0.057	[11.77, 11.81]
number of inactive combinations	2.08	0.133	[2.03, 2.14]

Table 5-11 Results derived from the model with an expanded set of orders

The results of supplying the assignment algorithm with an additional set of orders strengthen our opinion that the assignment algorithm is an adequate reflection of the assignment process in reality as the outcomes correspond to what can be expected from adding extra trips to the simulation model.

To evaluate the effects of using more frequent trip status updates in the situation where more trips are executed, an experiment similar to the one described in section 5.4.1 was performed. The results of this experiment are shown in table 5-12. From the results, we conclude that a significant difference does not exist between the situation without and the situation with more frequent status updates for any of the output variables. However, a positive trend is manifest in the comparison.

Although we are not able to demonstrate a significant difference between the current and the new situation, there are indications that an improvement may be possible. To prove this assumption, a new experiment involving less additional trips to be added to the model needs to be executed. The relative large number of additional trips included in the experiment influences the outcome considerably as a lot of orders delayed for at least one day obtained a more favourable penalty score compared to the other orders. The increase of 5.0 percent we used in this experiment was chosen arbitrarily, so an extra experiment that adds less than 5.0 percent additional trips to the model needs to be performed to investigate this effect. Another experiment that should be performed is to adjust the penalty score function with respect to orders that are delayed for at least one day. Due to time constraints, these experiments have yet to be carried out.

	current situation (n = 18)		status updates each hour (n = 18)			significance level	
	mean	s.d.	mean	s.d.	| t |	0.05	0.10
loaded kilometres	67.3	0.319	67.1	0.189	1.2	n.s.	n.s.
loading (constraint)	28.7	2.74	29.9	2.83	1.2	n.s.	n.s.
unloading (constraint)	45.3	9.17	46.3	6.86	0.38	n.s.	n.s.
loading	44.9	2.38	45.3	2.49	0.52	n.s.	n.s.
unloading	45.8	2.35	46.6	2.51	1.04	n.s.	n.s.
trips not assigned	39.6	9.57	35.3	9.65	1.34	n.s.	n.s.
effective speed	11.79	0.057	11.80	0.088	0.34	n.s.	n.s.
inactive combinations	2.08	0.133	2.15	0.158	1.35	n.s.	n.s.

$t_{0.025}(34) = 2.032$ $t_{0.05}(34) = 1.691$ n.s.: not significant

Table 5-12 Evaluation of effects for expanded set of orders

5.5 Summary and Conclusions

This chapter described the simulation study carried out for a haulier specialized in tanker transport, Rotterdam Tank Transport (RTT). A simulation model was developed departing from a description of the actual situation with regard to fleet management within RTT. Experiments were carried out with this simulation model to investigate the effects of using mobile communications on performance of trip execution. The experiments were designed using the properties of a Fleet Management System, derived from the FMS layout presented in chapter 4. The results of the simulation study are used to answer the third research question that deals with investigating the effects of using mobile communications on performance of trip execution.

The RTT simulation model was based on real data collected over a period of eight weeks, e.g., data on driving times, loading and unloading durations, transport orders, driver and equipment availability, etc. The trip execution process was modelled by defining a probability distribution for each trip component. Rules were incorporated into the simulation model to deal with opening times of locations, mandatory rest periods of drivers, the cleaning of tankers, etc. The fleet management process was modelled using a trip assignment algorithm, utilizing transport order data and actual trip status data to determine the following trip to be assigned to a transport combination. To model the real assignment process as accurately as possible, product classes, transport combination classes, and relationships between them were introduced, to prevent orders from being assigned to certain inadmissible or marginal types of transport combinations.

The simulation model was extensively validated using real data obtained from the analysis of the RTT planning department, by extensive debugging, by running test runs, and by presenting the animated simulation process to the dispatchers.

Four experiments were devised to analyze the effects of using mobile communications on the fleet management operations of RTT. The first experiment investigated the use of frequent status updates sent by the transport combination during trip execution. In the second experiment, the effect of sending pre-arrival notices containing the estimated time of arrival to the loading and unloading location was analyzed, assuming that excessive loading and unloading durations will no longer occur. The sending of pre-arrival notices is enabled by the availability of actual and accurate trip status information. The third and fourth experiment investigated the use of frequent trip status updates in combination with increased loading and unloading time restrictions and an increased amount of transport orders.

When using frequent trip status updates, only improvements in the effective speed of transport combinations and the number of trips not assigned, a measure of effectiveness in the simulation model, could be seen. The number of loaded kilometres, the loading and unloading time constraints, and the number of inactive transport combinations did not differ significantly. If loading and unloading durations become shorter and less deviated as a result of sending pre-arrival notices, all measures of performance improve excluding the number of loaded kilometres; as less time is spent on loading and unloading, the total distance driven empty increases to meet time restrictions.

If the number of time restrictions increases, the RTT simulation model did not manage to perform better when using frequent status updates. Therefore, we conclude that mobile communications can not be used to improve punctuality in the trip execution process. If the number of transport orders increased, no significant improvements were found in performance of trip execution, although the overall performance of the trip execution process tended to improve, excluding the number of loaded kilometres. Additional experiments with a different number of added transport orders have to be carried out to verify this trend.

CHAPTER 6

PROTOTYPE IMPLEMENTATION

6.1 Introduction

The results of chapter 5 indicate that using a fleet management system provides opportunities for improving the performance of the trip execution process for one particular haulier, Rotterdams Tank Transport. From the simulation study, however, it is clear that the introduction of more frequent trip status updates requires a mechanism that is capable of handling these updates automatically to a large extent. As can be concluded from the analysis of the messages exchanged between the transport combination and the planning department, handling incoming trip status updates (partial) automatically, i.e., without intervention of the dispatcher, is a prerequisite for avoiding overloading the dispatcher.

An implementation of a prototype system for a Fleet Management System is presented in this chapter. This prototype, called *FMSprototype* throughout the chapter, constitutes a prescriptive empirical model of the research approach. Section 1.5 mentions that one or more prescriptive empirical models can be constructed, comprising an implementation of the changes proposed in the prescriptive conceptual model. We decided to make one implementation of a prototype for an FMS, to be used in three experimental settings, thus actually constructing three prescriptive empirical models. This decision was made for financial reasons - building one prototype is cheaper than building three prototypes - and to facilitate a comparison of the three prescriptive empirical models. As a consequence of this decision, a prototype had to be built that was applicable to all three experimental settings. Thus, it will have a high level of generality. An evaluation of the FMS prototype is presented in chapter 7.

In general, a prototype will have limited functionality. For our case, this limitation found expression in the fact that the prototype did not support the trip *assignment* tasks of the dispatcher. This implementation choice was motivated by the fact that the three hauliers who participated in our research, did not have enough trucks equipped with mobile communication terminals to make inclusion of support for the trip assignment tasks sensible. When preparing a trip plan, all trucks performing the same kinds of operations in the same area should be considered. The number of trucks equipped by the participating hauliers - ranging from 5 to 25 percent of the whole fleet - did not justify including support of the assignment process in the prototype functionality. (It should be noted that at the time of our research, none of the Dutch hauliers within our field of research were fully equipped with mobile communication systems.)

Furthermore, when trying out a new kind of technology - mobile communications in road haulage - and a new way of working for information workers - providing support by means of a management-by-exception principle - one should not strive to build a complex system and one should try not to involve too many drivers in the first stage of the innovation process.

In section 6.2, the functionality of the FMS prototype is discussed, taking as a starting-point the layout for an FMS that was devised in chapter 4. Section 6.3 presents some important implementation considerations concerning the mobile communication system used, the user interface, the hardware used, and the design of the software. For a detailed specification of the FMS prototype functionality, see FMW (1993).

6.2 Prototype Functionality

The FMS prototype was designed mainly to support the trip execution monitoring tasks. The design of the prototype system is based on the FMS layout proposed in chapter 4. For the reasons mentioned in the previous section, not all of the support components included in the FMS layout will be implemented and the functionality of some of the support components will be adapted for the purpose of building the FMS prototype.

A schematic overview of the functionality of the FMS prototype is depicted in figure 6-1. The numbers in the circles representing the support components correspond to the FMS layout depicted in figure 4-6.

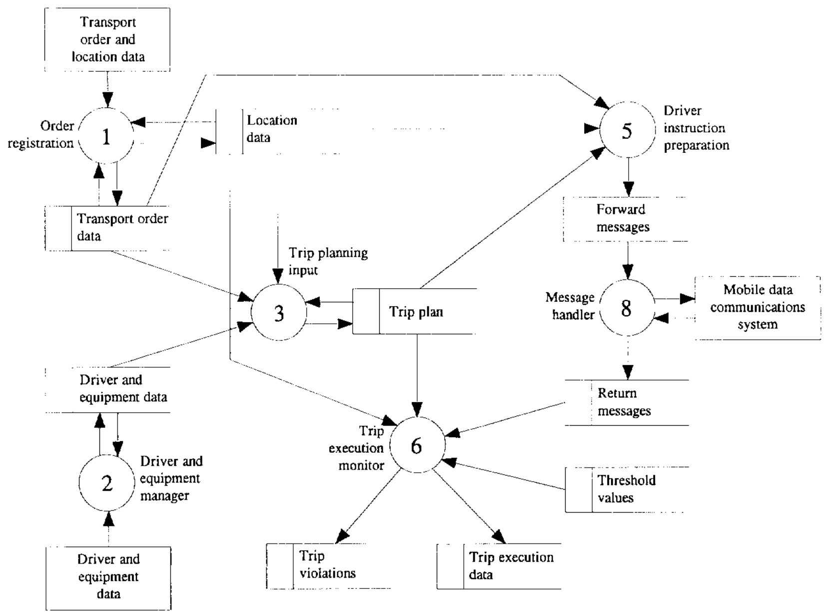

Figure 6-1 Data flow diagram of FMS prototype functionality

Compared to the layout of a fully functional FMS, several major differences attract attention. One, the support components RESCHEDULING SUPPORT and TRIP SETTLEMENT are omitted from the layout as they fall outside the scope of a prototype. (To keep the relationship between the layout for the fully functional FMS and the layout for the FMS prototype intact, the support components in figure 6-1 have not been renumbered.) Two, trip execution data and trip violations will not be used as input for other support components as the FMS prototype does not support the actual making of a trip plan. Three, location data are added to the layout to clarify the functionality of the FMS prototype. (In the layout for the fully functional FMS, they have been left out for reasons of clarity.)

When the functions that comprise the support components of the FMS prototype are rearranged, four *function groups* can be distinguished: *administrative* functions, *planning input* functions, *message handling* functions, and *trip execution monitoring* functions.

In the next sections, these function groups will be described in more detail. For each function group, a function hierarchy will be given. Finally, an adjusted data model for the FMS prototype will be presented.

6.2.1 Administrative Functions

The administrative functions deal with registering the data that is needed before the planning input process can be started. This function group comprises the functions that are included in the support components numbered 1 and 2: transport order registration, location data registration, and registration of driver and equipment data.

The function hierarchy for the administrative functions is presented in figure 6-2.

```
ADMINISTRATIVE FUNCTIONS
   |
   |── Transport order handling
   |       |── Input
   |       |── Change
   |       └── Report
   |               |── Transport order data
   |               └── Scheduled trips for transport order
   |
   |── Location handling
   |       |── Input
   |       |── Automatic extraction of co-ordinates
   |       |── Change
   |       |── Delete
   |       └── Report
   |
   |── Driver handling
   |       |── Input
   |       |── Change
   |       |── Delete
   |       |── Change availability
   |       └── Report
   |               |── Availability driver
   |               └── Available drivers in certain period
   |
   └── Equipment handling
           |── Input
           |── Change
           |── Delete
           |── Change availability
           └── Report
                   |── Availability equipment
                   └── Available equipment in certain period
```

Figure 6-2 Administrative functions for FMS prototype

In an operational environment, most of the data manipulation functions presented in figure 6-2 will already be incorporated in the overall information processing system (Assad 1988, Taylor 1990). As a consequence, data concerning transport orders, locations, drivers, and equipment are available from a corporate database in most haulage companies. Although this also holds in general for the three haulage companies that participate in our research, the decision is made not to interface the FMS prototype to the existing computer infrastructure for the following two reasons. One, as we choose to perform experiments with the prototype within three different haulage companies, connecting the FMS prototype to the existing hardware will require building three interfaces. Two, including an interface to the existing hardware in the FMS prototype will make the prototype too complex as an interface is already required to the mobile communication system. Therefore, the administrative functions require the information to be entered by the dispatcher using forms presented on a screen. As an example, the screen for registering transport order data is presented in figure 6-3. (The original screen layouts and the message layouts, discussed later, are originally documented in Dutch; for the purpose of readability, they have been translated as accurate as possible into English in this thesis. The contents of the screens and messages are based on actual data gathered from one of the experiments; confidential and personal information has been replaced by fictional data.)

```
Order id.           : 6205________
Loading date        : 18/08/92         Loading time  : 08:00
Unloading date      : 19/08/92         Unloading time: __:__
Qty. to load        : ________25        Qty. unit     : ton_
Qty. to unload      : ________25
Product             : Acetic Acid_________
Customer order id.  : 8124/9061-01
Customer name       : Dutch Chemicals BV______________
Customer phone      : _______________
```

Figure 6-3 Input screen for transport order data

In the FMS prototype, individual drivers and pieces of equipment are assigned to a trip instead of a transport combination. This reduction is made to simplify the actions the dispatcher has to perform to assign a driver and equipment to a trip, although it may result in more time being spent. An example of the input screen for driver and driver availability data is given in figure 6-4; the layout for the input screen for equipment and equipment availability data is similar.

The function for the registration of location data is implemented in a straightforward way. (See figure 6-5 for an example of the screen layout for entering location information.) The co-ordinates of a location, however, will be extracted from the trip status update sent by the transport combination from that particular location at the initial visit and recorded automatically (Assad 1988). This automatic process for extracting co-ordinates is enabled by the - incorporated - automatic vehicle location feature of the mobile communication system applied in the FMS prototype.

```
Driver id.   : 8700________
Driver name: Jansen________________________
Initials     : M.A._
Residence    : The Hague_____________________
Skills       : ADR____________     Preferences: NONE__________

Available from      Available to

  03/08/92           28/08/92
  21/09/92           23/10/92
  __/__/__           __/__/__
  __/__/__           __/__/__
  __/__/__           __/__/__
```

Figure 6-4 Input screen for driver and driver availability data

```
Location id.        : DUTCHEM_____
Location type       : Loading
Location name       : Dutch Chemicals Plant____
Address             : Petroleumweg 127________
Zip code            : 3124 DC_   City: Pernis___________________
Country             : The Netherlands_____
Time window - from: 07:00  Time window - to: 15:00
Remarks             : ______________________________________
Latitude            : _51  Longitude :  __4
Lat. min.           :  43  Long. min.:   30
Lat. sec.           :  _5  Long. sec.:   28
Lat. type           :   N  Long. type:    E
```

Figure 6-5 Input screen for location data

6.2.2 Trip Input Functions

The result of the trip assignment process is the assignment of a trip to a transport combination. As the FMS prototype does not support the trip assignment process itself - for reasons we discussed in section 6.1 - the functionality of the FMS prototype regarding the trip planning functions is restricted to trip *input* functions. The function hierarchy for the trip input functions is presented in figure 6-6.

```
TRIP INPUT FUNCTIONS
   |
   |-- General trip data handling
   |       |-- Input trip data
   |       |-- Change trip data
   |       └-- Delete trip
   |
   |-- Scheduled trip event handling
   |       |-- Add scheduled trip event
   |       |-- Change scheduled trip event
   |       └-- Delete scheduled trip event
   |
   |-- Handling assignment of equipment
   |       |-- Assign equipment
   |       |-- Change assignment of equipment
   |       └-- Delete assignment of equipment
   |
   |-- Check consistency of trip
   |
   └-- Report
           |-- Trip schedule
           |-- Schedule for driver
           |-- Schedule for equipment
           └-- Schedule for transport order
```

Figure 6-6 Planning input functions for FMS prototype

First, the general trip data is entered. These data comprise the company's trip identification number, the starting and finishing locations and point of times, the driver and the truck that are assigned to the trip, and possible special remarks relating to the trip. Next, after these data have been entered, the possible additional equipment, such as trailers and containers, can be entered. Finally, the *trip events* that are part of the trip should be scheduled. A trip event is an event taking place during the trip at a certain point of time that marks the starting of finishing of an activity or the activity itself. Within the FMS prototype, two trip event types that always have to be scheduled are the *start* and *finish* of a trip. As these two trip events determine in fact the trip and always have to be determined, the input of these two trip events is included in the general trip data screen.

The other trip events have to be scheduled separately. Two important activities in the trip execution process are the loading and the unloading of goods. As a certain period of time passes between the arrival at the loading or unloading location and the departure, four trip event types are introduced representing the arrival at or the departure from a loading or unloading location at a certain point of time.

The last two trip event types that are defined are the arrival at and the departure from another location, other than the types of locations already covered by the other trip event types. Examples of these other types of locations are frontier crossings and locations where the dispatcher expects the driver to report his or her current trip execution status.

Figure 6-7 gives an example of the input screen for the general trip data and the scheduled trip events. Each trip event is scheduled to take place on a certain date and at a certain time. Furthermore, a trip event can be related directly to the execution of a transport order, i.e., the scheduled trip event defines the arrival at a loading or unloading location. If this is the case, the transport order identification and the quantity of cargo to load or to unload have to be entered. The fields "Nr" and the "S" depict the serial number of the trip event and the status of the trip event.

```
Trip id.          : 6205______
Starting location: RTT______     Finishing location: HSG________
Starting date     : 18/08/92     Starting time      : 07:30
Finishing date    : 19/08/92     Finishing time     : 12:00
Driver id.        : 8700______   Truck: 4069_______
Remarks           : _______________________
Doc. handling     : Y            Reported N    Status trip 1

 Nr Location Order   Trip event type Date     Time  Qty. S

 _1 DUTCHEM_ 6205___ ARR. LOADING___ 18/08/92 08:00 __25 1
 _2 DUTCHEM_ 6205___ DEP. LOADING___ 18/08/92 11:30 ____ 1
 _3 HSG_____ 6205___ ARR. UNLOADING_ 19/08/92 10:00 __25 1
 __ ________ _______ _______________ ________ _____ ____ _
 __ ________ _______ _______________ ________ _____ ____ _
```

Figure 6-7 Input screen for general trip data and scheduled trip events

Although the FMS prototype can not assist the dispatcher in the preparation of the trip assignments, support is provided to check the consistency of the trips that have been defined. For example, possible errors that may be reported by performing the consistency check are:

- Trip and trip events are scheduled before the current date.
- A driver and/or equipment is assigned to a trip but is not available for the whole period defined by the starting and finishing points of time.
- A driver and/or equipment is assigned to a trip but is also assigned to at least one other trip in the period defined by the starting and finishing points of time.
- Trip events are not scheduled in chronological order.
- A trip event is scheduled before the starting of the trip or after the finishing of the trip.

- The starting time of a trip or the assignment of drivers and/or equipment is changed when the trip has started.

To define the consistency checks that have to be carried out, definitions 4-7 and 4-11 from chapter 4 are applied. For the purpose of developing a prototype with limited functionality, not all conditions that a trip plan must meet to be feasible are checked. Furthermore, performing the checks to determine if all service requirements are met or to determine if the intervals between scheduled trip events allow for performance of trip execution activities and transit between locations requires too much information to be included in the prototype and may not be explicitly available.

6.2.3 Message Handling Functions

Once the final trip assignment for a combination of driver and equipment has been determined, the driver should be informed about the trip he is supposed to carry out. In both the layout of the fully functional FMS and the layout of the FMS prototype, a support component DRIVER INSTRUCTION PREPARATION has been included for that purpose. The instruction of the driver was implemented in the FMS prototype by sending *preprogrammed messages* to the truck via the mobile communication system. A preprogrammed message is a message that contains both explaining text and fields to be filled in. Sending a preprogrammed message can be compared to the completion of a form. The motivation for using preprogrammed messages for communications between dispatcher and driver has been discussed in chapter 4. For each trip event type defined in the FMS prototype, a corresponding preprogrammed message was designed. The function of the DRIVER INSTRUCTION PREPARATION support component in the FMS prototype is to retrieve the relevant trip information from the FMS database and to "fill in" the preprogrammed message with this information in the appropriate fields. The messages that are sent from the FMS prototype to the truck are designated *forward messages*.

In figure 6-8, an example of a forward message containing the trip information needed for the start of a trip is presented. This message instructs the driver where to start the trip and on which time and which equipment should be used for carrying out the trip. Space for including special trip instructions or general remarks is also provided. While the forward message for the start of trip does not contain any information about loading or unloading of cargo, this information is contained in other preprogrammed forward messages. An example of a message containing both the information concerning the arrival at a loading location and information on the cargo to be loaded is given in figure 6-9.

```
START TRIP

TRIP IDENTIFICATION: 6205________
DRIVER: JANSEN, M.A.
EQUIPMENT: 4069_____________________

START DATE TRIP: 18/08
START TIME TRIP: 07:30
LOCATION: RTT_____________________
ADDRESS: BOTLEKWEG____________________
ZIP CODE: _________
CITY: ROTTERDAM_______________
COUNTRY: THE NETHERLANDS_________

SPECIAL TRIP INSTRUCTIONS:

________________________________________

REMARKS:

________________________________________
```

Figure 6-8 Forward preprogrammed message for start of trip

```
ARRIVAL LOADING

LOADING DATE: 18/08
LOADING TIME: 08:00
LOCATION: DUTCH CHEMICALS PLANT___
ADDRESS: PETROLEUMWEG 127______________
ZIP CODE: 3124 DC_
CITY: PERNIS__________________
COUNTRY: THE NETHERLANDS_________

PRODUCT     : ACETIC ACID_________
QUANTITY    : ____25
CARGO UNIT: TON_

CUSTOMER:
DUTCH CHEMICALS B.V.__________

CUSTOMER ORDER ID.:
8124/9061-01_____________

SPECIAL LOADING INSTRUCTIONS:

________________________________________

REMARKS:
________________________________________
```

Figure 6-9 Preprogrammed forward message for arrival at loading location

The driver is expected to respond to the preprogrammed messages forwarded by the FMS prototype by sending *preprogrammed return messages*. These messages are in fact identical to the preprogrammed messages sent by the FMS prototype. They only give the driver the opportunity to fill in the required fields instead of letting the driver make up his or her own report. Another feature of preprogrammed messages is that they can be *associated*, i.e., a preprogrammed forward message can be replied to with a specific preprogrammed return message. In the FMS prototype, for instance, the reply to the instruction to start a trip will be the message from the driver that the trip has started. Therefore, the driver does not need to know which specific message should be sent in this case; the only thing he or she has to do is to give a reply on the message "start trip" received. Figure 6-10 presents two examples of preprogrammed return messages. Information concerning the date and time the actual trip event occurred is included automatically when the driver sends the message. In the message on the right, additional space is reserved for the driver to report the actual amount of cargo that has been loaded.

```
TRIP STARTED

REMARKS:

____________________________
```

```
DEPARTURE LOADING LOCATION

QUANTITY OF CARGO LOADED:

__25.1

REMARKS:

DELAY DUE TO PRODUCT NOT_
READY ON TIME____________
```

Figure 6-10 Examples of preprogrammed return messages

To sum up, using the FMS prototype, the dispatcher will instruct the driver of a transport combination about his new trip assignment and the - scheduled - trip event that proceeds from carrying out this trip. Once a trip event has occurred, the driver sends a reply message through the mobile communication system, confirming that the trip event has actually taken place.

To clarify the information exchange between the dispatcher - using the FMS prototype - and the driver, a diagram giving an example of the message exchange pattern, is presented in figure 6-11. Usually, before the trip actually starts, the dispatcher will instruct the driver about the scheduled trip events. When changes are made to the trip plan, however, the dispatcher is able to send an updated message containing the modified data of the scheduled trip event to the driver.

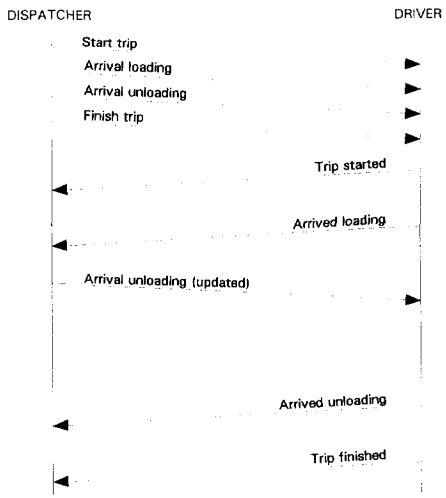

Figure 6-11 Example of information exchange

The function hierarchy of the message handling functions is presented in figure 6-12. This hierarchy contains functions for sending and receiving preprogrammed messages utilized by the FMS prototype, designated FMS messages, a function for sending a general message, not directly related to a scheduled trip event, and a function for the maintenance of the preprogrammed messages. To establish the interface with the mobile communication system, an additional function handling the incoming and the outbound messages is included.

```
MESSAGE HANDLING FUNCTIONS
   ├── Send forward FMS message
   ├── Send general message
   ├── Receive FMS message
   ├── Interface messages to and from
   │     mobile communication system
   └── Maintain preprogrammed messages
```

Figure 6-12 Message handling functions of FMS prototype

6.2.4 Trip Execution Monitoring Functions

The last group of functions to be explained is the group of functions relating to support of the trip execution monitoring process. The evaluation of the management-by-exception principle, which is used to support this process, is in fact the main purpose of building and testing the FMS prototype. In this context, the other functions described in the previous three sections, should be regarded as *auxiliary* in the sense that they enable the TRIP EXECUTION MONITOR support component to function.

The FMS prototype is aimed at signalling the *schedule deviations* that have been defined in definitions 4-12 and 4-13. Deviations that exceed a certain, predetermined threshold value, will be signalled by the FMS prototype. To decrease the complexity of the FMS prototype, the signalling of deviations that result from an estimated finishing time of a certain activity is not implemented. The other types of deviations defined in definition 4-15 through definition 4-17, e.g., the service requirement violations and the overlap violations, will also not be implemented. This limitation of the prototype's functionality is also prompted by the fact that for signalling these violations additional information is needed which may not explicitly be known or is time-consuming to enter into the prototype.

The function hierarchy of the trip execution monitoring functions is presented in figure 6-13.

```
TRIP EXECUTION MONITORING FUNCTIONS
  |
  |-- Match actual trip event with trip plan
  |
  |-- Signal
  |      |-- Schedule violation
  |      |-- Distance deviations
  |      |-- Procedural errors
  |      `-- General messages and remarks
  |
  |-- Report
  |      |-- Delayed trip events
  |      |-- Signals
  |      `-- Trips being executed
  |
  `-- Maintain threshold values
```

Figure 6-13 Trip execution monitoring functions of FMS prototype

The first function to be executed is the matching of the return messages, that represent an actual trip event, with the trip plan that is currently present in the FMS prototype. Each return message is sent by a truck, so the matching process starts by inspecting the trips that are scheduled for this truck. If the actual trip event can be matched to a trip, the next step is to determine whether the actual trip event can be matched to a scheduled trip event. If this is successful, the scheduled point of time for the trip event will be compared to the actual point of time. If the possible deviation exceeds the predetermined threshold value for the trip event type the trip event in question relates to, the deviation will be signalled to the dispatcher.

If the actual trip event can not be matched to a scheduled trip event, but does relate to the starting or finishing of a trip, a comparison between the point of time the actual trip event took place and the scheduled time for the start or finish of the trip is carried out. Further, if a deviation exceeding the threshold value is found, it will be signalled. Once a deviation has been determined by the system, a message will be displayed on the screen and an acoustic signal will be produced by the FMS prototype. After confirmation by the dispatcher, a screen with the relevant information of the deviation will be displayed. An example of this screen is shown in figure 6-14. The information on the actual trip event is presented above the double-dashed line. Under this line, information about the scheduled trip event or the scheduled trip is presented, depending on the type of entity the actual trip event could be matched to. If an actual trip event can not be matched to a scheduled trip event, or to a scheduled trip, the second half of the screen is not shown. In that case, the fields concerning the scheduled trip (event) in the first half of the screen show dummy values.

```
Deviation type         : Schedule Deviation__
Date / time            : 19/08/92  14:30
FMS message number     : 14
Position               : _48 08 25 N   _11 48 56 E
Equipment              : 4069________
Scheduled trip         : 6205________
Scheduled trip event:  : _3
Quantity               : ______
Remarks                : ______________________________

================== SCHEDULED TRIP EVENT ==================
Trip id             : 6205________
Trip event nr.      : _3
Status trip event:  : 1
Location            : HSG________
Trip event type     : Arr._Unloading
Date                : 19/08/92
Time                : 10:00
Order id            : 6205________
Quantity            : ___25
```

Figure 6-14 Screen layout for signalling of deviation

If an actual trip event can not be matched to a scheduled trip event or to a scheduled trip, the driver that has sent the FMS return message in which the actual trip event is contained, has probably made an error. We will refer to these kinds of errors as *procedural errors*. Other procedural errors appear when the driver reports a trip event that has already been reported again or when the driver sends the reply messages in the wrong order. The procedural errors will be signalled in the same way as deviations from the trip plan are signalled.

Apart from replying to the forward FMS messages the driver receives, he or she has the possibility of sending a general message to the FMS prototype. As this message should contain important information for the dispatcher, it is treated in the same way as the appearance of a deviation. Furthermore, the driver has to the possibility of including some remarks in the return FMS messages.

The signalling of deviations that arise during driving from a certain location to the location where a trip event will take place is also implemented in the prototype (see point 4 of definition 4-12). As we assume the presence of AVL functionality in the mobile communication system, the equipment on-board the truck is able to send regular position co-ordinates to the FMS prototype. When the position update for a moving truck falls inside a certain radius of the location where the truck's next scheduled trip event is, a comparison is made between the point of time of the position update and the point of time at which the trip event in question is scheduled. If the comparison results in the predetermined threshold value being exceeded, a *distance deviation* will be signalled. (The threshold value chosen should correspond to the time needed for the transport combination to cover a distance equal to the radius of the imaginary circle around the location.) This method of using position updates close to the location to be visited next, supports the dispatcher in determining the transport combinations that will probably arrive too late - or too early.

When the driver of transport combination that arrives too late at the next location to be visited, sends a return FMS message, a schedule deviation will be signalled. In real life, this deviation will already have been signalled, as once the time allowed for the trip event, i.e., the scheduled time increased with the threshold value, is exceeded the dispatcher will be aware the a delay must occur. Therefore, the FMS prototype includes a function for reporting *delayed* trip events. A delayed trip event is defined as a trip event that should already have taken place, even when the threshold value for this trip event is taken into account, but for which as yet no return FMS message has been received. The screen layout for the report of a delayed trip event is presented in figure 6-15. The top part of the screen shows the general trip data of the trip to which the scheduled trip event belongs. The bottom part of the screen shows the data of the scheduled trip event itself. The scheduled trip event type and the associated threshold value are shown in the box.

To be able to change the threshold values of the different trip event types, as may be required by changing circumstances or preferences of the dispatcher using the FMS prototype, a maintenance function is included in the function hierarchy of the trip execution monitoring functions.

```
Trip id.          : 6205______
Starting location: RTT_______   Finishing location: HSG_____
Starting date     : 18/08/92     Starting time      : 07:30
Finishing date    : 19/08/92     Finishing time     : 12:00
Driver id.        : 8700______   Truck: 4069_______
Remarks           : ____________________________
Doc. handling     : Y            Reported Y     Status trip 2

 ------------------------------------------
| Finish Trip_________        1 HR.___     |
 ------------------------------------------
```

Figure 6-15 Screen layout for reporting delayed trip events

6.2.5 Data Model for FMS Prototype

In section 4.4, an elementary data model for fleet management is presented. For the development of the prototype of a Fleet Management System, this data model is modified to model the entities that play a role in the FMS prototype. Due to simplifications in the prototype's functionality and the introduction of the actual trip events and the trip event types, we arrived at the data model for the FMS prototype that is depicted in figure 6-16.

As trips are assigned to drivers and equipment separately in the prototype, the transport combination entity is left out of the data model. Furthermore, the entities for customers, product, loading order, and unloading order are deleted from the data model as the information about these entities is contained in the entity for the transport order.

An actual trip event can be related to a scheduled trip event, a trip, or the piece of equipment that sent the message reporting the actual trip event. An actual trip event is usually related to a scheduled trip event. If this is not possible, the FMS prototype relates the actual trip event to the trip currently being executed. If this also fails, the actual trip event is related to the piece of equipment that sent the message.

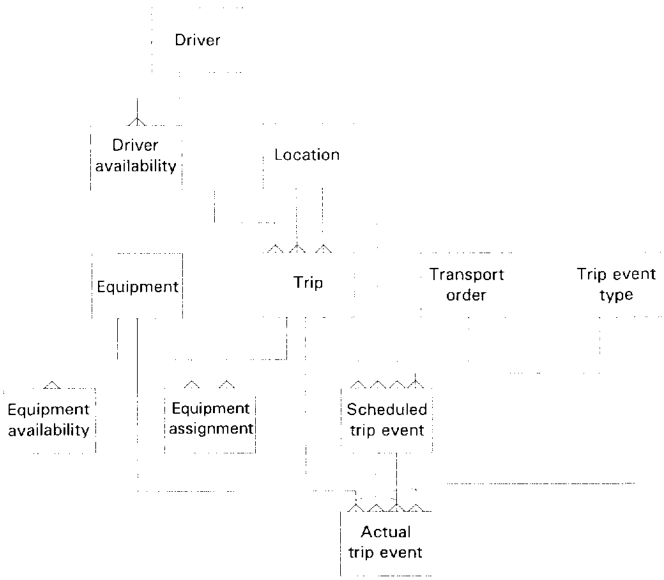

Figure 6-16 Data model diagram for FMS prototype

6.3 Implementation Considerations

In this section, we will review some of the implementation decisions that had to be made during the development of the FMS prototype.

First of all, a mobile communication system must be selected that allows the FMS messages to be sent. The mobile communication system has to meet four requirements: (1) communications with the trucks must be possible throughout the greater part of Europe, (2) the system must be able to support the use of the preprogrammed data messages, (3) the interface to the hardware platform that is used for developing the FMS prototype must be specified clearly to avoid problems with connecting the two different systems, and (4) the communication system must be capable of AVL. A mobile - satellite - communication system that fulfils these requirements is the EutelTRACS™ system (Jacobs *et al.* 1991). (Outside Europe, this system is known as the OmniTRACS™ system.) Our choice of using this system was also governed by the fact that the three participating haulage companies are already using the EutelTRACS™ system to communicate with their drivers. It should be noted, however, that the system is used on a limited scale within these companies. We emphasize that the choice of this communication system was only made within the context of developing the FMS prototype. The concept of a Fleet Management System as delineated in the chapters 4 and 6 can be realized using any mobile communication system that meets the four requirements mentioned earlier in this paragraph.

As the FMS prototype actually consists of two applications, the *FMS kernel* that provides support for the administrative and the trip planning input functions, and the *signalling module* that takes care of the message handling, interfacing, and trip execution monitoring functions, which should be able to be executed simultaneously and independently of each other, a UNIX™ operating system was chosen to run the applications. The applications itself were developed using Progress™, a fourth generation language including a database management system. The hardware used for the implementation of the FMS prototype was an 80486 Personal Computer.

The user interface of the FMS prototype is implemented in a straightforward manner. As can be seen from the screen layouts presented earlier in this chapter, data are entered into the system using form fill-in screens (Shneiderman 1987). These form fill-in screens simplify data entry and are similar to the paper fill-in forms that all dispatchers are familiar with. These screens are accessed through a menu structure which is organized around the four function groups described in section 6.2. A major disadvantage of the combination of the menu structure and fill-in form screens is that switching between input screens becomes cumbersome. The decisive advantage of this type of user interface is the ease of implementation which makes it suitable for prototype development.

Graphic representation of positions of trucks is generally considered to be important for supporting fleet management tasks (Belardo *et al.* 1985, Sena 1990). Although it was not included in the FMS prototype functionality, dispatchers were offered this type of graphic support during the field test using the standard software package of the EutelTRACS™ system.

CHAPTER 7

APPLYING A FLEET MANAGEMENT SYSTEM

7.1 Introduction

Chapter 6 presented a prototype implementation of the Fleet Management System, a layout for which was devised in chapter 4. The prototype implementation, the *FMS prototype*, provides support mainly for the trip execution monitoring tasks of the dispatcher. This limitation of the prototype's functionality was applied for reasons explained in section 6.1.

With the FMS prototype, experiments were carried out in co-operation with the three road haulage companies involved in the construction of the descriptive conceptual model described in chapter 3. The prototype was installed and used in the same planning departments investigated earlier. The purpose of carrying out the experiments with the FMS prototype was to answer the second research question. This questions deals with establishing the effects of using mobile communications on organizational performance at the micro level:

> *What are the effects of using mobile communications on the performance of the execution of the dispatcher's tasks?*

This chapter the evaluates the experiments with the FMS prototype and will, therefore, answer our second research question. Furthermore, the results of the experiments will contribute to specifying possible improvements and modifications of the overall FMS layout presented in chapter 4.

Section 7.2 describes the experimental design of the experiments with the FMS prototype. Section 7.3 discusses the utilization of the FMS prototype during the experiments. Section 7.4 presents the evaluation of the overall FMS functionality, both for the FMS prototype and the fully functional FMS system. Specific support for the trip execution monitoring tasks is evaluated in detail in section 7.5. Section 7.6 summarizes the results of the evaluation of the FMS experiments.

7.2 Experimental Design

The FMS prototype comprises the prescriptive empirical model, the fourth and last model to be built according to the research approach presented in chapter 1. The prescriptive empirical model represents the situation "to-be" for a specific problem situation, based on the changes proposed by the prescriptive conceptual model.

To measure the effects of introducing mobile communications in supporting the dispatcher's fleet management tasks, and thus the effects of using a Fleet Management System at the planning department of road haulage company, a comparison between the situation before and the situation after the introduction of the FMS must be made, i.e., the performances of the descriptive empirical models and the prescriptive empirical models at the micro level of the haulage company must be compared. An experiment using the FMS prototype should provide insight into the effects expected when using Fleet Management Systems.

In chapter 5, the effects of using mobile communications on organizational performance at the meso level were analyzed for one particular haulier, RTT, using a simulation approach. From the results of this analysis, it is clear that support needs to be provided to handle incoming trip status updates. The mechanism chosen to accomplish this support is the management-by-exception principle explained in chapter 4. Thus, the second purpose of carrying out an experiment with the FMS prototype is to analyze the feasibility of using FMSs, that apply a management-by-exception principle to handle incoming trip status updates, in daily fleet management practice.

To operationalize the performance measures resulting from the use of the FMS, we discuss some theory on the relationship of the utilization and the performance of information systems within organizations. Generally, information system use in organizations is aimed at providing added value to the existing processes. Availability of information systems alone does not offer organizations any direct value. Utilization of an information system is the means through which information technology can affect organizational performance (Le Blanc and Kozar 1990). System utilization is a requisite but not a sufficient condition for information technology to influence performance in a desirable manner. The relationship between information technology, the utilization of a system and the performance of a system is expressed in figure 7-1 (Trice and Treacy 1988).

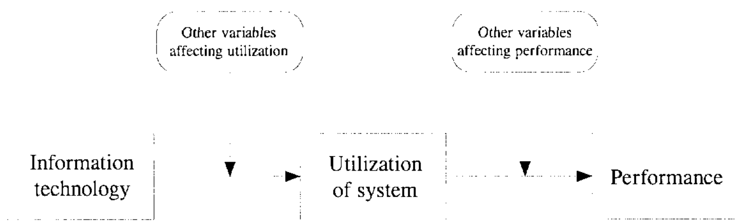

Figure 7-1 Relationship between information technology, utilization, and performance

Utilization serves as the intervening variable between the opportunities offered by information technology and the performance of the information system. Utilization and performance of the information system can be influenced by other factors than the use of information technology.

When this theory is applied to the experiment to be set up for using the FMS prototype, we conclude that first of all we must assure that the FMS prototype will actually be used before performance of the FMS prototype can be measured. Further, during the evaluation of the FMS prototype use, the actual use of the system needs to be measured. Thus, the performance measured can be validated through actual use of the FMS prototype.

To measure the actual performance of using the FMS prototype, an operational *field test* of the FMS prototype must be carried out (Sharda *et al.* 1988). This test must be performed in a real-life environment, supporting actual tasks of the dispatcher. The field test is an example of an *empirical evaluation method* that was used to study the effects of using FMSs because it allows evaluation of an information system in an operational setting with reasonable experimenter control (Adelman 1992). Another empirical evaluation method often applied, performing an *experiment*, was not considered for evaluation of the FMS prototype as it requires comprehensive experimenter control that could not be achieved in the operational environment the prototype was evaluated in, where only a part of all the transport combinations was involved in the test.

The relatively small number of transport combinations involved in the test, is a major limitation for the operational field test. Furthermore, as argued in the previous chapter, the FMS prototype has only limited functionality, which implies that the dispatcher is not able to abandon the original way of working entirely. Therefore, making a quantitative comparison between performance before and after the introduction of the FMS prototype was not feasible.

We will take the dispatcher's assessment of the system's value, compared to the performance in the situation "as-is", as the performance measure. Although this *user information satisfaction* measure is a substitute for objective measurement of information system performance, it is believed that this assessment method is adequate (Fuglseth and Stabell 1985, Ives *et al.* 1983, Keen and Scott Morton 1978). A questionnaire was devised to elicit the dispatcher's opinion on various aspects of the FMS prototype. After completion of the field test, the dispatcher filled in the questionnaire, after which the results of the questionnaire were discussed using a structured interview. The questionnaire contains nine categories of questions, which the dispatcher has to answer by marking one of five symbols, indicating a range of increasing relevance where the precise meaning of the symbol was dependent on the question asked.

As the dispatcher acquired general experience on the use of Fleet Management Systems during the field test, we regard the dispatcher as an expert able to give an opinion not only about the FMS prototype, with its limited functionality, but also on a fully functional Fleet Management System as proposed in chapter 4. Therefore, dispatchers were asked to give their opinion on the difference in time spent on carrying out the FMS supported functions and the contribution made by the support provided by the FMS functions for both the FMS prototype and the fully functional FMS system.

When setting up the field test to evaluate the FMS prototype, much attention was paid to achieving acceptance and use of the system by the dispatchers. In a planned organizational change process, user involvement is essential for the success of the implementation (Ives and Olson 1984). If the change is of temporary nature and results in additional work to be done by the employees involved, as was actually the case when performing the field test with the FMS prototype, the supervision of the change process is even more important. Moreover, because of extensive supervision of the field tests by the experimenter, additional information on the performance and the functionality of the FMS prototype was obtained, e.g., through anecdotical evidence (Keen and Scott Morton 1978).

The following activities were carried out in the field test of the FMS prototype:

- *Instruction of drivers*. Driver instruction on how to interpret FMS messages received from the FMS prototype and how and when to respond to these messages was considered very important, as return FMS messages provide essential trip status information for the FMS prototype. Drivers were instructed in the use of the preprogrammed FMS messages both at meetings and in the cabins of their trucks with the mobile communication terminal to hand. (It is important to note that all the drivers were generally acquainted with the use of mobile satellite data communications.)

- *Instruction of dispatchers.* Dispatchers were trained to use the FMS prototype during meetings where the overall objectives of the field test and how it would affect the dispatchers were explained. A concise presentation of the FMS prototype functionality was given. The instruction of the dispatchers and the drivers and the dispatcher was for the greater part, aimed at motivating the employees involved in the field test.

- *Actual field test of the FMS prototype.* The actual field test of the FMS prototype was divided in three parts. The first two weeks of the test were used to give the dispatcher a comprehensive training of using the FMS prototype in an operational setting. The second part of the test allowed the dispatcher to build up experience in use of the FMS prototype. In the third and last part, use of the FMS prototype was intensified.

- *Supervision and support of actual field test.* During the actual field test of the FMS prototype, a lot of attention was given to providing an adequate supervision and support for the dispatcher using the system. The primary objectives were to maintain the dispatchers' and drivers' motivation and to solve possible problems in an early stage. Furthermore, in two of the three field tests we carried out, additional man-power was provided to support the dispatcher using the FMS prototype. In these field tests, an employee of the haulage company supported the dispatcher operating the FMS prototype, when necessary. This improved experimental control of the field test.

- *Evaluation of field test.* The field test was evaluated using the method described earlier in this section. As three haulage companies were involved, three field tests were carried out. The limited number of field tests does not allow rigorous statistical analysis of the results given by the dispatchers.

For evaluation purposes, the FMS prototype functionality has been extended with a *logging facility*, recording data on the actual use of the FMS prototype, such as points of times of entry of trip data, the number of changes made to a trip plan, etc.

For a comprehensive evaluation of the field test, an evaluation of the FMS functionality, and possible enhancements to this functionality, see Schrijver (1993a, 1993b).

7.3 Utilization of FMS Prototype

In the previous section, we have shown that utilization of an information system plays an important role in determining the information system's performance. To summarize the relationship between utilization and performance of an information system, it can be stated that a good utilization of an information system is a necessary but insufficient requirement. In the evaluation of the field test with the FMS prototype, we used the utilization of the FMS prototype to confirm our conclusions regarding the measured performance of the system by the dispatcher. The utilization of the FMS prototype was established independently of the dispatcher's opinion of the functioning of the system, so that subjective measures for the system's utilization, such as self-reported measurements of the dispatcher, can be avoided as much as possible (Trice and Treacy 1988).

Before we start a discussion of the actual utilization, we will evaluate the experimental setting of the field test. In the questionnaires filled in by the dispatcher, one set of questions dealt with the evaluation of a number of general factors that may have influenced the outcomes of the field test. We will refrain from presenting the extensive results of these questions and give a short evaluation of the experimental setting instead. The evaluation of the experimental setting is supported by the experiences gained during the field tests.

The motivation of the dispatchers and the drivers proved generally to be reasonable at the start of the field tests and only declined slightly during the field test in most cases. The training and instruction for both the dispatchers and the drivers was highly valued and the supervision and support provided during the field test was much appreciated. Furthermore, the FMS prototype was mainly used to partially support the regular tasks carried out by the dispatcher. The execution of the tasks of the dispatcher principally comprised in the FMS prototype's functionality, was only in a limited number of cases left entirely to the FMS prototype. As a result, the FMS prototype was employed mainly alongside the dispatcher's regular tasks.

The first utilization measure to be examined is the number of transport combinations involved in the field test. A transport combination was said to be involved in the field test when a trip assignment for the transport combination in question was entered into the FMS prototype. The length of the field test, the total number of transport combinations involved in the field tests, the number of transport combinations involved for one week, and the period a particular transport combination was involved in the field test are presented in table 7-1. In the tables presented in this chapter, the following abbreviations are used to denote the haulage companies involved in the field test: "RTT" for Rotterdams Tank Transport, "VA" for Van Amerongen, and "HV" for Harry Vos.

		RTT	VA	HV
Length of field test (in weeks)		7	7	7
Total number of transport combinations involved		17	9	5
Number of transport combinations involved (per week)	mean	9.4	3.7	3.9
	s.d.	2.3	3.3	1.7
Period of involvement per transport combination (in weeks)	mean	3.9	2.9	5.4
	s.d.	2.1	1.3	1.1

Table 7-1 Field test length and number of transport combinations involved

From the figures given in table 7-1, it can be seen that the average period of involvement per transport combination is significantly less than the whole period of the field test - which was seven weeks. Several reasons exist for this deviation:

- The FMS prototype installed at the planning department of Van Amerongen suffered from a major technical problem, which resulted in the system being used less frequently. As a consequence of the malfunction, the motivation of the dispatchers and the drivers decreased rapidly to a level at which continuation of the field test would be counterproductive.

- Some drivers became so demotivated, that they refused to participate further in the field test.

- Some transport combinations were lost to the field test because of unexpected vacations or sickness or the original driver was replaced temporarily by another driver not instructed on the use of FMS messages.

Figure 7-2 shows the number of trips monitored by the dispatchers using the FMS prototype during the field tests. This figure distinguishes between trips issued to a driver using forward FMS messages, but for which no return FMS messages were received from the driver (*trips issued*), trips that were issued and for which at least one return FMS message was received, excluding the finish of a trip (*trips started*), and trips that were issued and for which at least the return FMS message reporting the finish of a trip was received (*trips finished*).

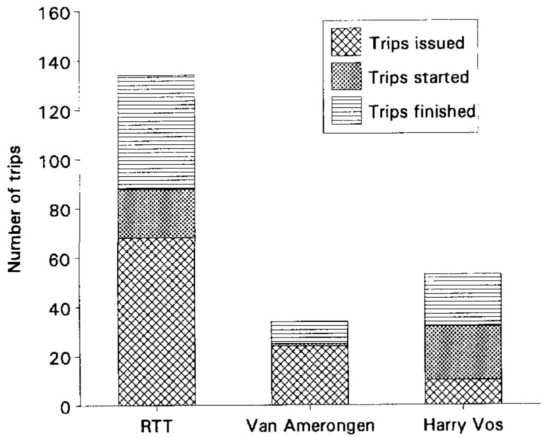

Figure 7-2 Number of trips involved in field tests

From figure 7-2, it can be concluded that the FMS prototype was used adequately by the dispatchers, although it is also clear from figure 7-2 that the FMS prototype utilization at Van Amerongen was unsatisfactory - because of the technical problems mentioned earlier in this section. This conclusion is supported by the figures presented in table 7-2, which shows the total number of trips entered in the FMS prototype, the average number of trips per transport combination involved per week, and the average number of trip events defined per trip, not including the start and finish of a trip because the dispatcher is obliged to define these two trip events for each trip. Therefore, this figure represents a measure of the utilization of the FMS prototype. (The total number of trips depicted in figure 7-2 differs slightly from the value given in table 7-2 as a trip assignment may have been re-issued to the driver because of changes and not all trips entered into the system are actually issued to drivers.)

		RTT	VA	HV
Total number of trips		139	38	61
Number of trips per transport combination (per week)	mean	2.1	1.5	2.2
	s.d.	1.3	0.58	1.0
Number of trip events per trip (exclusive of start and finish of trip)	mean	2.1	2.3	0.43
	s.d.	0.76	2.1	0.90

Table 7-2 Overview of number of trips and trip events

As a prototype is not a fully operational system, all the FMS prototypes used in the field tests suffered from technical problems. For instance, the limited robustness of the system required the system to be restarted occasionally. Although this led to problems in communications with the drivers in some cases, we are of opinion that in general the FMS prototype was used in such a way during the field tests, that an adequate evaluation is possible.

The forward FMS messages containing trip instructions were not always answered by the driver and as the functioning of the management-by-exception principle is dependent on received return FMS messages, the collaboration of the drivers was very important. The utilization of sending the return FMS messages by the drivers was analyzed by determining the response percentage of messages per trip event type for the field test period. Table 7-3 presents the total number of forward FMS messages and the percentage of return FMS messages sent by the drivers.

	RTT		Van Amerongen		Harry Vos	
	Number	Response	Number	Response	Number	Response
Start trip	124	45 %	34	12 %	55	84 %
Arrival loading	12	58 %	-	-	2	-
Departure loading	121	58 %	1	-	2	50 %
Arrival location	8	25 %	32	16 %	7	29 %
Departure location	-	-	9	22 %	-	-
Arrival unloading	120	43 %	34	15 %	8	38 %
Departure unloading	-	-	5	60 %	4	25 %
Finish trip	124	43 %	33	24 %	40	75 %
	509	47 %	148	18 %	118	72 %

Table 7-3 Response to forward FMS messages by the drivers

In 45 percent of the cases, the FMS message was not answered by the driver. Three reasons are put forward to explain this observation: (1) not all drivers were fully motivated to co-operate, (2) some minor problems occurred during the sending of FMS messages to the transport combination resulting in the loss of some messages, and (3) the method to be followed by the driver for sending return messages proved to be error-prone, which caused many messages to be discarded by the message handling functions of the FMS prototype.

Another measure of utilization is the extent to which changes were made to the trip plan once the initial trip plan data were entered into the FMS prototype. As the FMS prototype was fitted out with a logging facility, data regarding changes in trips and trip events were recorded. The results of the analysis of these data are given in table 7-4, which shows the total number of trips changed after the initial trip data were entered and confirmed by the dispatcher, the number of changes performed on each changed trip, the total number of trip events changed after the initial trip event data were entered and confirmed, and the number of changes performed on each changed trip event. The percentages shown between brackets indicate the amount of changed trips or trip events in proportion to the total number of trips or trip events.

		RTT	VA	HV
Total number of trips that were changed		12 (8.6 %)	1 (2.6 %)	29 (48 %)
Number of changes per changed trip	mean	1.4	4.0	1.9
	s.d.	0.51	0	1.1
Total number of trip events that were changed		7 (2.4 %)	1 (1.1 %)	1 (3.8 %)
Number of changes per changed trip event	mean	1.0	1.0	1.0
	s.d.	0	0	0

Table 7-4 Number of changes in trip plan

In most of the cases, few changes were made to the trip plan already present in the FMS prototype. An explanation for this is that the trips were entered into the FMS prototype just before the actual start of the trip so the trip assignment concerned was almost finalized. An additional analysis carried out for the RTT field test reveals that the moment of entering the trip data into the system lay just before or even after the actual starting time of the trip (Schrijver 1993a, p. 28). When the trip is started early in the morning, the trip data are entered at the end of the previous day, after preparing the final trip plan for the following day.

To determine the frequency of use of the FMS prototype functions, a subjective, qualitative method was used, the analyses presented earlier in this section are based on objective, quantitative data. Dispatchers were asked to give an estimate of the frequency of use for the set of functions implemented in the FMS prototype. To limit the set of functions to be judged, not all functions described in the function hierarchies defined in chapter 6 were included as they could be clustered into groups. Other functions from these function hierarchies were performed automatically by the system, so they can not be included in this analysis.

In table 7-5, the frequencies of use of the FMS prototype functions are given. It should be emphasized that the estimates given by the dispatchers represent a relative value and should not be regarded as representing an absolute estimate of the frequency of use. The signs "——", "—" , "□", "+", and "++" are used to indicate the relative frequency of use, indicating a range of frequencies from "hardly or not used" to "very often used". The estimates that are contained in the table have been validated by the observations made during the intensive supervision of the field test.

	Frequency of use				
	——	—	□	+	++
Transport order handling		1			2
Location handling					3
Driver handling		2		1	
Equipment handling	1	2			
General trip data handling				1	2
Scheduled trip event handling				1	2
Handling assignment of equipment	2		1		
Change or delete scheduled trip, scheduled trip event, or assignment of equipment		1		2	
Report trip schedule (per trip, driver, equipment, or transport order)		1		1	1
Sending forward FMS and general messages				2	1
Report delayed trip events			1	2	
Report trip being executed		1		1	1
Report previous signals	1		1	1	

Table 7-5 Frequency of use of FMS prototype functions

Table 7-5 shows that the functions concerning the handling and assignment of equipment and the handling of driver data were not carried out frequently. As the transport combinations in general do not change very often, changes in the assignment of equipment data are not made frequently. Furthermore, availability of equipment does not seem to play a major role in trip execution monitoring. Availability of the driver is a more important issue, because the driver can have certain appointments requiring him to return on time, but this information is often only known and used implicitly.

The other functions of the FMS prototype were used often or very often, which indicates a sufficient utilization of the system's functions. The frequency of use for reporting previous signals may seem to be relatively low, but it should be noted that each signal, once it occurs, is reported to the dispatcher in an active way.

To conclude, we regard the utilization of the FMS prototype to be sufficient to make a valid assessment of the system's performance. Although the field test suffered from some technical problems, the utilization of the FMS prototype proved to be reasonably high. The utilization in the field test performed at Van Amerongen differs significantly from the other two field tests due to a major technical problem. Solving this (complex) problem turned out not to be worthwhile as the motivation of the drivers and the dispatchers was already fairly low, due to the malfunction of the FMS prototype, and would be decreased further by the time the field test could be resumed. Nevertheless, we include the results of the field test at Van Amerongen in the evaluation as we are of opinion that the dispatchers involved in this field test were able to give a satisfactory assessment of the FMS functions' performance.

7.4 Performance of Fleet Management System

This section answers the question to what extent the performance of the dispatcher's tasks is influenced by the use of mobile communications, in particular by using the Fleet Management System according to the layout devised in chapter 4.

As the FMS field test could not be carried out on a large scale, only a minor part of the fleet was involved, and because of the limited functionality of the FMS prototype, it was not possible to obtain generalizable, quantitative results for the performance of the Fleet Management System. To obtain insight into the effects to be expected from FMSs on performance of the dispatcher's tasks, after the field test dispatchers were asked to give an opinion about the time spent to carrying out the FMS supported functions and the contribution the support provided by the FMS prototype made to their ability to carry out their tasks. We regard the dispatcher to be an expert able to give an opinion about the performance aspects of using FMSs as he or she acquired general experience in the use of FMSs during the field test. We consider the dispatcher to be able to judge the time spent on carrying out functions and to judge the contribution of these functions to an imaginary system extrapolated from the functionality of the FMS prototype.

The fully functional FMS system must be based upon the functionality of the FMS prototype. Modifications that must be made to this prototype are improved reliability, improved robustness, and an improved user interface. The FMS prototype functionality will be extended with additional functionality derived from the support components omitted from the layout for the FMS prototype (see figure 6-1). These extensions are listed in table 7-6. For each of these extensions, the dispatchers were asked to judge feasibility. In this context, we regard the feasibility of an extension to refer to the practicality of implementing the proposed extension and the usefulness of implementing the extension.

	Feasibility				
	−−	−	□	+	++
Equip entire fleet with mobile (satellite) data communications				1	2
Integration with personnel information system to obtain driver (availability) information			1	1	1
Integration with maintenance information system to obtain equipment (availability) information			1	2	
Integration with order processing information system to obtain information on transport orders, customers, and locations					3
Provide support to handle general trip data, scheduled trip events, and assignment of equipment				1	2
Integration with finance and accounting information system (trip settlement)			1	1	1

Table 7-6 Feasibility of extensions to FMS prototype

From this table, we conclude that, in general, the extensions we propose to include in the FMS prototype are considered feasible by the dispatchers. Equipping the entire fleet with mobile data communications and integrating the order processing information system are considered to be prerequisites to developing a fully functional FMS system. Integration with the personnel and maintenance information systems turns out to be less important because the amount of data to be obtained from these systems is limited and these data do not contribute directly, in most cases, to the trip execution monitoring tasks.

Table 7-7 presents the estimated time spent and the estimated time to be spent on carrying out the dispatcher's tasks that correspond to the FMS functions when using the FMS prototype and the fully functional FMS system. The estimated time spent and the time expected to be spent are given relative to the time spent when an FMS is not used. A " > " sign indicates that more time is spent on carrying out the function in question when using the FMS prototype or system; a " < " sign indicates a decrease in time spent. The "□" sign is used to indicate that no significant difference in time spent is observed. If an observation is missing or if the dispatcher was not able to give a judgement on the time spent, the "..." sign is given.

	Estimated time spent using FMS prototype						Estimates of time expected to be spent using FMS system					
	≪	<	□	>	≫	...	≪	<	□	>	≫	...
Transport order handling					3			2	1			
Location handling					3			1	1			1
Driver handling			1			2	1		2			
Equipment handling			1			2	1	1	1			
General trip data handling			1	1	1			1	2			
Scheduled trip event handling				1	2			1	2			
Assignment of equipment			2			1			2	1		
Change or delete trip, etc.				3				2	1			
Report trip schedule			3					2	1			
Sending messages			1		1	1		1	1	1		
Report delayed trip events			1	1		1	1	1	1			
Report trip being executed		3					1	1	1			
Report signals		2		1				1	2			

Table 7-7 Time spent on carrying out dispatcher's tasks, supported by FMS functions

From the dispatchers' opinion of the time spent using the FMS prototype, it is evident that for most cases, using the prototype used more of the dispatcher's time. Only the time needed to report trips currently being executed decreased, as information about these trips was contained in the FMS prototype, this information is not available instantly at present. The functions for handling transport order and location data require much more time than in the existing situation as this information had to be gathered from different sources during the field tests, sometimes without the use of a computerized information system. General trip data and scheduled trip event handling also took more time as for the FMS prototype the dispatcher must make the trip schedule explicit by defining exact points of time when the trip events must take place.

For all functions in the FMS system, the time spent on carrying out tasks decreased or remained equal. When using the FMS system, six of the dispatcher's tasks listed in table 7-7 will take less time to carry out; the other seven tasks can be carried out in about the same time. Through the establishment of integration with the order processing information system, time spent on transport order and location data handling decreases considerably. A decrease in time spent on general trip data and scheduled trip event handling is achieved by providing support in defining and scheduling the trip events (see table 7-6). A Wilcoxon matched-pairs signed-ranks test was carried out to determine whether a significant difference exists between the times spent on executing tasks in the FMS prototype and the FMS system (Frude 1987, Neter *et al.* 1988). This test yielded a probability of 0.0003 for the two groups having the same median value. Thus, at a significance level of 0.05, it can clearly be seen that using the FMS system will result in less time being spent than when using the FMS prototype.

The contribution of a FMS function was determined by having the dispatcher assess the support provided by the FMS prototype or FMS system for carrying out his or her corresponding task. Compared to the set of functions involved in the analysis of time spending, the set of functions for which the contribution needs to be established is smaller. Five functions are excluded from the original set of functions as they are auxiliary and therefore can essentially have no contribution to the trip execution monitoring process. These functions include the transport order, location, driver, and equipment data handling functions and the function for changing and modifying the trip schedule. Another function, the consistency check of a trip, was added to the set of functions to be assessed. This function was not investigated during the analysis of time spending as it is executed without interaction with the user.

Table 7-8 presents the results of the analysis of the contribution that support, provided by the FMS functions, gives to carrying out the dispatcher's tasks. A "□" sign indicates that the function does not contribute to the corresponding task, a "+" sign indicates a minor, but significant contribution, a major contribution is indicated by a "++".

In the FMS prototype, only the functions that form the kernel, the implementation of the management-by-exception principle, are considered to contribute significantly to the carrying out of tasks. Further, the contribution of the function that provides a report of the trip schedule turns out to be relatively high. An explanation for this is the fact that all relevant data of a trip schedule can be looked up in the FMS prototype in an easy and quick way that was not possible before. The other functions do not make a contribution to an improved performance of the tasks. The (active) reporting of signals will be discussed in more detail in section 7.5.

	Estimated contribution using FMS prototype					Estimates of contribution to be expected using FMS system				
	□	□/+	+	+/++	++	□	□/+	+	+/++	++
Trip data handling	1	1	1				1	2		
Trip event handling		2	1				1	1	1	
Assignment of equipment	2	1					1	2		
Check consistency trip		2	1			1		2		
Report trip schedule		1	1	1			1	1	1	
Sending messages		1	2				1	1	1	
Report delayed trip events			1	2					1	2
Report trip being executed			1	1	1					3
Report signals			2	1				1		2

Table 7-8 Contribution of FMS functions to carrying out of dispatcher's tasks

The functions of the fully functional FMS system are all considered to contribute more to the performance of tasks than the corresponding functions of the FMS prototype. Only general trip data handling, handling of assignment of equipment, checking of trip consistency and sending and receiving of messages are still considered to contribute less than the other functions. The reason for this is that some of these functions require trip schedule information to be made explicit and entered into the system that is experienced to be a drawback by the dispatchers and the other functions are considered cumbersome to execute.

A Wilcoxon test was carried out to determine whether a significant difference exists between the contribution made by the FMS prototype and the FMS system. This test yielded a probability of 0.0011 for the two groups having the same median value.

Thus, at a significance level of 0.05, it can clearly be seen that using the FMS system gives a higher contribution than when the FMS prototype is used.

From the analyses of the time spent on carrying out functions and the contribution FMS functions can have to the dispatcher's tasks, we conclude that when using a fully functional FMS system, the time spent on carrying out fleet management tasks should decrease when compared to not using an FMS. The contribution of the FMS functions to the execution of the dispatcher's tasks has proven to be positive so an increase in the performance of the dispatcher's tasks can also be expected.

7.5 Evaluation of Trip Execution Monitoring Support

This section discusses the evaluation of the FMS functionality directed at supporting the dispatcher in carrying out trip execution monitoring tasks. The main purpose of the FMS prototype was to support these tasks by utilizing a management-by-exception principle. The other functions of the FMS prototype were primarily meant to enable the management-by-exception principle to be utilized. Therefore, evaluation of the support for the trip execution monitoring tasks will be discussed separately from overall FMS prototype functionality and in more detail, in this section. For evaluation of overall FMS functionality, see section 7.4.

Before we discuss the evaluation of the management-by-exception principle, we will briefly recapitulate the basics of applying this principle to support trip execution monitoring, see chapter 4 for a comprehensive explanation.

Each trip to be monitored using the FMS prototype contains at least two trip events, the start and the finish of the trip. Additional trip events, such as departure from a loading location or arrival at an unloading location, may be defined optionally. For each trip event, a date and time is scheduled. If the deviation between the actual date and time a trip event takes places and the scheduled date and time exceeds a predetermined threshold value, a signal will be given, warning the dispatcher that a major deviation from the trip schedule has been detected.

In the next section, general experiences with the use of the management-exception principle and the number of actual signals fired during the field tests, the "actual usage" of the principle, are discussed. Next, the contribution of the different signal types and the importance of signalling deviations for certain trip event types are examined. Finally, a limited quantitative analysis of the scheduled and actual trip event data is given.

7.5.1 General Experiences

In general, dispatchers seem to be satisfied with the idea of supporting trip execution monitoring using the management-by-exception principle (Schrijver 1993a, pp. 39-40). They tend, however, to regard the use of this principle as more suitable to other road haulage businesses than their own. This observation may be explained by the fact that employees in the road haulage business often view their own business as unique. Dispatchers consider the signalling of deviations from the trip plan to be valuable support for their monitoring tasks. Defining trip events during a trip, scheduled on a certain date and time, however, proves to be laborious for the dispatchers. The field tests showed that is not easy for them to schedule a trip event for an exact point of time in such a way that a possible signalling of a deviation from this scheduled time will be useful. The value of signalling deviations once a trip event has taken place seems to be limited. Dispatchers are in need of a mechanism that allows them to anticipate deviations from scheduled trip events. As an example, the driver is often asked to report an estimated time of finishing an unloading process at an early stage of this process, if the transport combination will be available to carry out a new assignment on completion. Dispatchers further criticized the exchange of trip status reports using the preprogrammed, associated messages. The current way of sending and receiving these FMS messages caused too many errors to be made by the drivers in the field tests, resulting in the driver sending a return FMS message too late, sending an incorrect return FMS message, or sending no return FMS message at all.

The need to receive estimates of actual trip event times also finds expression in the analysis made of the messages that were sent not using the FMS prototype. Although the drivers and dispatchers were instructed to use the FMS messages as much as possible, several extra messages had to be sent by both the dispatchers and the drivers to assure continuation of the regular trip execution process. These messages have been analyzed and categorized (Schrijver 1993a, pp. 41-42). From this analysis, it appeared that a fairly large number of messages were sent requesting or providing additional information concerning the transport order or location data. Further, a number of messages dealt with requesting and reporting trip status updates during the carrying out of an activity; sending trip status updates only at the start or the end of an activity proved to be inadequate.

We conclude that the set of FMS messages currently defined is not powerful enough to comprise all information exchange between the dispatchers and the drivers. It is doubtful, however, if it is possible to capture all information exchange within one single, easy to use, set of FMS messages. In future developments, special attention needs to be paid to providing the driver with correct and complete information and to include FMS messages capable of reporting trip status execution updates while carrying out an activity.

7.5.2 Evaluation of Signal Use

The actual use of the FMS prototype during the field test resulted in the signalling of numerous deviations. The number of signals provides a measure for the utilization of the FMS prototype, in addition to the utilization measures already investigated in section 7.3. Figure 7-3 presents an overview of the actual number of signals for each field test.

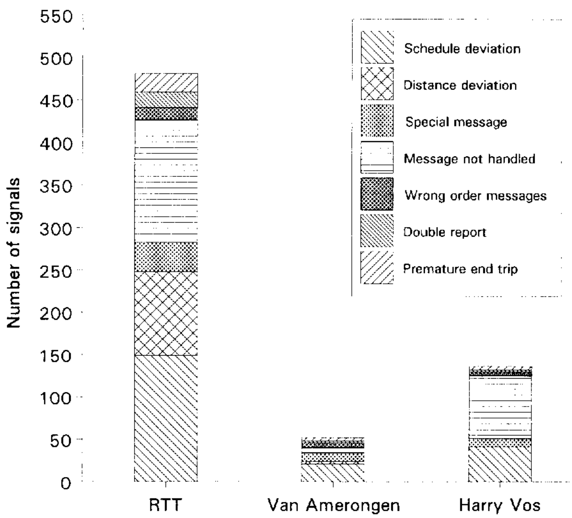

Figure 7-3 Overview of actual number of signals

In figure 7-3, the signals are categorized by the type of signal. The signal types defined in the FMS prototype can be divided into three groups:

1. *Deviation signals*. This group consists of the signals that actually report a deviation from the trip schedule, i.e., *schedule deviation* and *distance deviation*.

2. *Message signals*. The signals reporting a message sent by the driver, a general FMS message or a filled in "remarks" field within one of the other FMS messages, fall into this group (*special message*).

3. *Procedural error signals*. This group consists of signals probably caused by incorrect usage of FMS messages by the driver. (Procedural errors can be also caused by carrying out the trip assignment incorrectly, although this may be less likely to occur.) The following procedural errors are recognized and signalized by the FMS prototype:

- *Message not handled.* The return FMS message can not be recognized as a reply to a previously sent forward FMS message.
- *Wrong order messages.* The return FMS messages are sent in a wrong order or a reply belonging to a previous trip event has not been sent.
- *Double report.* More than one FMS return message belonging to the same trip event has been sent.
- *Premature end trip.* A return FMS message indicating the end of a trip has been received before all other trip events belonging to that trip are reported.

From the analysis of the number of signals given during the field tests, we conclude that the actual usage of the FMS prototype will allow us to make an adequate evaluation of the feasibility of using the management-by-exception principle. This conclusion adds to the conclusion we drew in section 7.3 that the overall utilization of the FMS prototype allows for a reliable assessment of overall FMS functionality.

In the questionnaire for the evaluation of the field tests, the dispatchers were asked to give an opinion about the contribution the seven signal types made to their trip execution monitoring tasks. The results of this question are presented in table 7-9.

	Contribution					
	□	□/+	+	+/++	++	...
Schedule deviation				2	1	
Distance deviation		1	1	1		
Special message			1	2		
Message not handled			1		2	
Wrong order			2			1
Double report	1		1			1
Premature end trip	1		1	1		

Table 7-9 Contribution of signal types to trip execution monitoring

From table 7-9, it is clear that the schedule and distance deviation signals and the special messages signals from the driver are considered to be important for the trip execution monitoring process. Distance deviation signals are estimated to be somewhat more important as this type of signal allows anticipation of a schedule deviation that will probably occur. Although the procedural signals do not contribute directly to the monitoring of the trip plan, these are considered to be important because they contain useful information about the actual trip execution process. (It has to be emphasized, and this is also perceived by the dispatchers, that these signals detract from the original objective of using the management-by-exception principle, which should provide more accurate trip execution information while not overloading the dispatcher with an abundance of messages.) The estimates for the last signal types are not given as the dispatchers were not able to give an agreed judgement due to the small number of these signal types.

Deviation signals occur when a deviation is detected between the actual and scheduled time of a trip event. As the importance of reporting a deviation is expected to differ for each trip event type, dispatchers were asked in the questionnaire to indicate the importance of signalling a deviation for each trip event type, see table 7-10.

	Contribution				
	□	□/+	+	+/++	++
Start trip		2	1		
Arrival loading		1	1		1
Departure loading				1	2
Arrival location		1	1		2
Departure location			1	1	1
Arrival unloading				2	1
Departure unloading			1		2
Finish trip		3			

Table 7-10 Importance of deviation signals for trip event types

The deviations that occur during the start and finish of a trip prove to be not very important in trip execution monitoring. Most dispatchers usually only define the points of time for loading and unloading of goods. In a few cases, the start of a trip is defined explicitly, e.g., when a driver does not start the trip directly from the haulage company's home base. The arrival at the loading location and an arbitrary other type of location, except for those explicitly mentioned, are considered more important. The most important deviations are considered to be deviations that occur when departing from a location, as processes carried out at these locations have been finished and thus the transport combinations are no longer subject to the possible, more or less, unpredictable delays that occur during these processes, as the goods to be transported have reached their final destination and the transport combination will be available within reasonable time to carry out the next trip (with FTL transport).

According to the dispatchers, the set of trip event types defined in the FMS prototype proves to be suitable for obtaining reasonable insight into the actual trip execution process. The forward FMS messages, that directly relate to the set of trip event type, contain insufficient information to instruct the driver adequately; in most cases, specific transport order data, that could not be included in the standard FMS messages, had to be sent to the driver separately. This statement of the dispatchers is supported by the analysis of the messages sent not using the FMS prototype. Another disadvantage of using FMS messages, as each message refers to one individual trip event, is that the driver receives several FMS messages to instruct him or her to carry out one trip. This turned out to be confusing for the driver as he or she has no clear view on the trip events to be executed, certainly as both actual instructions and instruction for trips already finished can be present at the same time on the mobile communications terminal of the driver.

7.5.3 Analysis of Trip Efficiency

The previous sections explored the qualitative aspects of using the FMS prototype in the field. Emphasis was given to the opinion of the dispatchers on different aspects of the FMS prototype. This section presents a limited analysis of *trip efficiency*, involving the use of the FMS prototype in the RTT field test. Trip efficiency is defined as the extent to which the dispatcher is able accurately to schedule the trip events within a trip. The RTT field test was selected to carry out the trip efficiency analysis because of the fairly large number of transport combinations involved in the test, these delivered a data set containing enough observations to make a quantitative analysis.

The aim of the analysis of trip efficiency was to examine the difference between actual and scheduled trip event times. These data are recorded in the FMS prototype which allows us to make an analysis. In daily practice, it is very hard to carry out such a comparison as the trip schedule prepared by the dispatcher is not made explicit and recorded. By examining the difference between scheduled and actual trip execution, we want to confirm that adequate support of trip execution monitoring using deviation signals is appropriate given the stochasticity in actual trip event occurrences.

The analyses were carried out by examining the trip event data set of RTT containing the scheduled and actual trip event date and time for all trip events. If the actual data of a trip event was not available, i.e., a driver did not send the reply for that trip event, the trip event was deleted from the data set. Next, all trip events containing obvious errors were deleted from the data set. These errors were introduced by drivers reporting the trip event (much) too late. The final data set that results from this procedure contained 203 observations.

In the first analysis, the difference between the scheduled and the actual time was determined for all trip events. Next, a frequency distribution of these time differences was made for each trip event type. Figure 7-4 shows the results of this analysis. The distributions for three trip event types are not presented due to insufficient data.

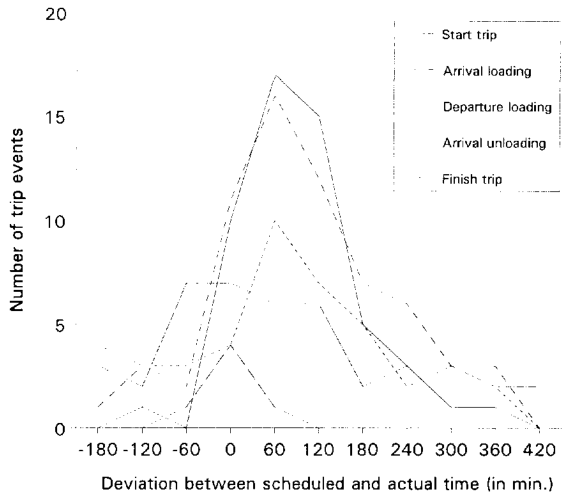

Figure 7-4 Distribution of deviations between scheduled and actual trip events

From the results of our analysis, it is clear that significant deviations from the scheduled trip event time occur during trip execution. Further, the average deviation from the scheduled time increases as the trip progresses. To illustrate the magnitude of these deviations, the average 66.0 and the standard deviation 116 have been calculated. Two remarks must be made, however, on the results presented in figure 7-4. One, due to experimental effect, in several cases, drivers sent their return FMS messages at a later point of time than the actual occurrence of the trip event. Thus, if figure 7-4 was based on real, actual data, it would be shifted to the left somewhat. Two, in fleet management practice, if a (significant) deviation occurs during the execution of a trip, the dispatcher will adjust the scheduled times of the trip events still to be carried out, in such a way that a feasible trip schedule is again obtained. During the FMS field tests, however, this way of working was not applied by the dispatchers explicitly so that no changes were made to the actual trip schedule present in the system. Therefore, no data on adjusted trip event times, initiated by the occurrence of a significant deviation, are available.

To examine the consequences of adjusting a trip schedule if deviations occurred at a previous trip event were taken into account, a second analysis was carried out. For each pair of consecutive trip events, the differences between the actual and the scheduled trip event times were calculated. Next, these time differences, in fact the durations, were drawn in a scatter diagram shown in figure 7-5. By examining these time differences, the difference between the actual occurrence and the scheduled occurrence for a particular trip event is "corrected" for the deviation that occurred in the past.

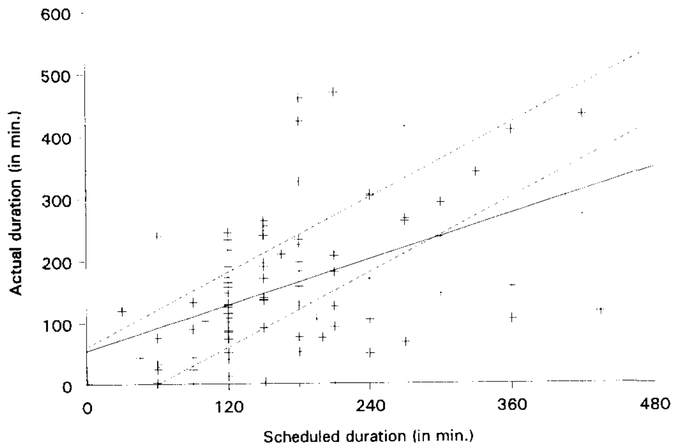

Figure 7-5 Scatter diagram of scheduled and actual durations

The dashed lines define the area where a deviation between the actual and the scheduled trip event time would not lead to a schedule violation. The threshold value used in determining this area is one hour, a value that was commonly used by the dispatchers during the FMS field test. A large number of observations, 43 percent of the total observations depicted in figure 7-5, fall outside the area marked by the dashed lines, causing a schedule violation to occur. The solid line depicts a regression line for the actual duration as a function of the scheduled duration. The slope of the regression line, which is 0.61, is remarkably lower than one would expect the slope to be, at about one. This indicates that dispatchers tend to estimate the duration between two trip events to be larger than it actually will be. The results of this analysis should be treated with caution as the depicted regression line only partially explains the relationship between the difference in scheduled time and the difference in actual time (the determination co-efficient R^2 has the value 0.24).

We emphasize that the results of the two quantitative analyses presented in this section are mainly indicative due to the limited number of observations available and because of the occurrence of some experimenter effects. From these preliminary results, however, we conclude that when using regular trip execution status updates and having these updates handled by the FMS system, it must be possible to reduce the slack that the dispatcher introduces into the trip schedule to cope with uncertainty in the trip execution. Efficiency of the trip execution process is expected to be improved by reducing this slack. The analyses justify the use of frequent trip status updates to signal deviations from the trip plan timely.

7.6 Conclusions

This section gives an evaluation of an application of a Fleet Management System in road transport. A prototype system of an FMS was used during a field test of seven weeks at the planning departments of three Dutch haulage companies. This evaluation aimed at answering our second research question concerning the effects of using Fleet Management Systems on the performance of the dispatcher's tasks.

The evaluation of this FMS prototype was organized the following way. One, the actual utilization of the prototype system was established. Two, the performance of the FMS prototype was determined. Thus, the measured performance was validated using the actual utilization of the FMS prototype.

The actual utilization of the FMS prototype during the field test turned out to be satisfactory, despite some minor technical problems, so a valid estimation of the performance of the system could be made. As only a part of the entire fleet could be involved in the field test and the FMS prototype had limited functionality, the performance of the FMS prototype, expressed in both as time spent on executing tasks supported by FMS functions and the contribution of these functions to the execution of the dispatcher's tasks, were measured by assessment of the dispatcher. The performance of a fully functional FMS system, as defined by the FMS layout presented in chapter 4, was measured by having the dispatcher extrapolate the performance of the FMS prototype. We concluded that using an FMS system will result in a significant contribution to the dispatcher's tasks whilst decreasing the time spent on carrying out these trip execution monitoring tasks.

The implementation of the management-by-exception principle, actually the kernel of the FMS, proved to be satisfactory for trip execution monitoring. Dispatchers attached considerable value to the signalling of deviations that actually occurred during the field tests. Some minor modifications were proposed to obtain more detailed insight into the trip execution process.

A limited quantitative analysis of the differences between the scheduled and actual trip time events showed that applying a management-by-exception principle to support the trip execution monitoring tasks of the dispatchers is legitimate as major deviations between actual trip execution and trip schedule occur frequently. Further, a preliminary investigation showed that dispatchers apparently introduce slack into the scheduled trip event times to cope with uncertainty in the trip schedule. If regular trip status updates are used, the slack can probably be reduced, resulting in a more efficient trip execution process.

During the field tests, the method of having the dispatchers assess the value of the FMS functions qualitatively, delivered useful results. In a few cases, the assessments of the various dispatchers did not agree so an overall assessment on the subject in question could not be given. This strengthens our opinion that the concept of an FMS as described in this dissertation provides a good basis to developing FMSs in the area of road transport businesses selected in the initial stage of our research.

CHAPTER **8**

EPILOGUE

8.1 Introduction

In this dissertation, we have addressed the issue of providing support to fleet management of transport operations to increase performance in professional road transport business. We observed that the road transport business, a major industry in the Netherlands, is operating in a currently changing, turbulent, and hostile environment, and therefore has to cope with several problems, e.g., decreased profitability, increased customer demands, and increased traffic congestion. These problems have given rise to unsatisfactory performance in the hauliers' transport operations.

Our research was directed towards providing support for dispatchers' fleet management activities at a haulier's planning department. Fleet management is defined as "real-time planning, monitoring, and controlling of fleet movements and operations aimed at minimizing operating costs and satisfying customer demands". We noticed the existence of a major discrepancy between actual trip execution status and perceived trip execution status by dispatchers and drivers using the telephone network; it is possible to report trip status updates and to give instructions only at specific points of time. Due to this discrepancy, the execution of fleet management tasks is hampered, affecting both fleet management and trip execution performance.

We argued that using mobile communications could provide a solution to the problems found. Actual trip execution status information should become more accurate and complete through the use of frequent trip status updates, and thus should lead to a more effective trip schedule. In our research, we investigated the use of mobile communications to support the dispatcher's fleet management tasks. We restricted the research area to professional road transport performing FTL transport, including a limited form of LTL operations, for various reasons.

In this epilogue, the research questions we stated at the beginning of our research are evaluated and the research findings are presented. We end this thesis with some concluding remarks with regard to the generalization of our research findings and possible future research to be conducted.

8.2 Research Findings

In this section, we will answer the research sub-questions we proposed in chapter 1. The first sub-question addresses the question of how to integrate mobile communications into an information system supporting the dispatcher's tasks:

> *What are the characteristics of an information system that makes use of mobile communications for supporting the fleet management process?*

In chapter 2, we ascertained, based on reports from the literature, theory on information systems supporting decision processes, and personal observations from the road transport business, that current information systems for vehicle routing and scheduling could not be applied to solve the problems identified in fleet management operations. Chapter 4 presented a layout for an information system integrating mobile communications, the Fleet Management System, and applying a management-by-exception principle to achieve real-time fleet management. The FMS layout is based on a comprehensive analysis of the existing situation with regard to fleet management in three haulage companies, presented in chapter 3. This layout utilizes proven existing information technology. Therefore, we find it plausible to assume that the FMS layout provides an adequate description of the characteristics asked for in the research question.

In another sub-question, we were concerned about trip execution performance when introducing frequent trip status updates, enabled by mobile communications:

> *What are the effects of using mobile communications on performance of the trip execution process?*

To answer this question, we carried out a simulation study for one particular haulier performing tanker transport, described in chapter 5. We concluded from this study that only minor improvements in trip execution efficiency can be achieved by using frequent trip status updates but that no improvements in trip punctuality and the number of loaded kilometres can be expected. When frequent trip status updates are used to notify the loading or unloading location a short time ahead about the estimated time of arrival of a transport combination, the result is shorter and less deviated loading and unloading durations, and major improvements to all performance measures investigated. This is evidence for introducing *chain integration* into the physical distribution system, provided that the necessary adjustments to the fleet management and trip execution processes can be made. Once established, it will probably yield a satisfactory increase in trip execution performance given the use of mobile communications.

The results of the simulation study further indicated clearly that support is needed for the dispatcher to handle the increased amount of trip status updates to avoid overloading. Determination of the feasibility of providing this support is covered by our last sub-question to be answered. This sub-question was directed to the effects mobile communications may have on the dispatcher and was formulated as follows:

> *What are the effects of using mobile communications on the performance of the execution of the dispatcher's tasks?*

To answer this question, a prototype of the FMS was developed, based on the FMS layout devised in chapter 4, and field tests were carried out in the three haulage companies involved in the development of our descriptive conceptual model of fleet management using the FMS prototype, see chapter 6 and 7. From the field tests we concluded that none of the support components implemented in the FMS prototype can be regarded as superfluous or irrelevant for support of fleet management and that implementation of the support components is feasible. The management-by-exception principle was considered by the dispatchers to contribute significantly to trip execution monitoring tasks. These two conclusions affirm the answer given to our first sub-question that the FMS layout provides an adequate description of the characteristics of an information system incorporating mobile communications.

With regard to the performance of the dispatcher's tasks, we concluded that using the FMS will result in less time spent in the execution of tasks, especially in the execution of trip execution monitoring tasks. Hence, efficiency of the dispatcher's tasks will increase. Changes in effectiveness of the dispatcher's tasks have been investigated by asking the dispatchers involved in the field tests to judge the contribution of the support provided by the FMS. This judgement was made by comparing the carrying out of their tasks in the existing situation to the carrying out of these tasks supported by the FMS. From this analysis, a major positive contribution to the support of almost all tasks was seen. Therefore, we assume an increase of the effectiveness of dispatchers' fleet management tasks.

An additional analysis carried out during one of the field tests showed that dispatchers tend to include slack time between the scheduled trip events to anticipate possible future delays. With the introduction of frequent trip status updates, slack time can be reduced thus obtaining a more efficient trip schedule.

The three sub-questions answered in the previous paragraphs, each directed to a certain aspect of using mobile communications, were derived from the main research question proposed in chapter 1. Having discussed the answers to the three sub-questions, we now come to an answer to this main research question. The main research question is repeated here for convenience sake:

Is it possible to improve the performance of the fleet management process in professional road transport business by the use of mobile communications?

We conclude that performance of fleet management and trip execution operations can be improved by using mobile communications. Performance can probably be even more improved, however, by establishing chain integration in the physical distribution system.

We must emphasize that the results of our research are only valid when taking into account the following three limitations. One, we restricted the research area to professional FTL transport including limited LTL transport. Despite this restriction, we belief that the management-by-exception principle may also be applied to other transport business as we found no indication that this principle would only apply to FTL transport. In practice, the feasibility of using the principle for trips with a large number of loads to be picked up and delivered may perhaps be questioned in view of the fact that the judgements on performance improvement by dispatchers participating in the field test addressing LTL transport were less positive than the judgements of the other dispatchers.

Two, the analysis of trip execution efficiency was performed for one haulier, specialized in tanker transport. Hence, we are not able to generalize the results of this analysis. The trip execution process of the haulier was characterized by major deviations in trip component durations that caused the unsatisfactory performance. We have shown in the simulation study that no major improvements in trip execution performance can be obtained by using frequent trip status updates until re-engineering of the trip execution process is considered. We expect that using frequent trip status updates for other hauliers that also have to contend with major deviations in trip component durations, will not improve trip execution performance considerably.

Results of other researches addressing similar problems point in the same direction (De Jong 1992, Verbraeck 1991).

Three, the analysis of the efficiency of dispatchers' tasks was based on experience obtained in field tests carried out with three hauliers operating in our particular research area. Although the field tests with the FMS prototype only involved three hauliers, we find it plausible to assume that the results obtained will also hold for other hauliers operating in the same research area. The FMS prototype was based on a prescriptive conceptual model including the general characteristics of the three hauliers involved in our research. Therefore, the prescriptive conceptual model is expected to cover more hauliers than just the three on which the model was based.

8.3 Future Research

We conclude this epilogue by identifying possibilities for future research.

Intervention of current trip execution was not investigated in our research. The effects of the arrival of rush orders and possible reassigning of trips, in relation to using mobile communications, were not examined. When the time interval between issuing a transport order and the starting time of the transport order diminishes, mobile communications may be used to reassign trips to increase performance. Reassigning trips is one of the topics needing to be addressed in future research.

The field tests described in chapter 7 were carried out using an FMS prototype with limited functionality. To investigate the feasibility of a fully functional FMS and the resulting effects on performance, an implementation of an FMS including all support components and offering full functionality for each support component, tailored to a specific problem situation, needs to be made and tested in practice. Therefore, integration with other information systems, such as the order processing information system, needs to be established. Adequate support needs to be provided for the driver to send frequent trip status updates. With the newly implemented FMS, pilots have to be performed involving all transport combinations operating within the trip execution process of a haulier. In this way, the functionality of the support components offering support for (re)scheduling of trips can be evaluated and empirical data on the effects on performance can be obtained and analyzed.

Another pilot we propose is to establish chain integration in reality by sending notification of estimated times of arrival to (a number of) loading and unloading locations. The purpose of such a pilot is to gain insight into the possibility of decreasing uncertainty in loading and unloading durations when making arrangements with the loading or unloading locations or by speeding up the preparations needed to load or unload the cargo. This pilot can probably be integrated with the application of Electronic Data Interchange between hauliers, customers, and locations, see Streng (1993).

Another item for further research we propose, is an investigation of the feasibility of applying the FMS layout to other road transport business, e.g., full LTL transport and courier services, or to passenger transport, e.g., public transport and taxi cab services. Although moving goods differs from moving people, clear similarities in the principles of the two types of transportation can be identified.

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SAMENVATTING

Inleiding

Het goederenvervoer over de weg neemt een belangrijke (economische) plaats in tijdens het transport van goederen van plaats van oorsprong naar plaats van bestemming. Vrachtwagens hebben de mogelijkheid om op flexibele wijze goederen op te halen en af te leveren volgens door de opdrachtgever gestelde eisen.

De laatste tijd ziet het goederenvervoer over de weg zich gesteld voor grote problemen. Door de toegenomen aandacht voor het milieu wordt er steeds meer druk uitgeoefend op de vervoerders om het aantal leeg gereden kilometers te verminderen en bij te dragen aan een verminderde uitstoot van luchtverontreinigende stoffen. Door sterk toegenomen kosten en (relatief) gelijkblijvende opbrengsten is de rentabiliteit van het transport sterk gedaald. Verder worden door de opdrachtgevers hogere eisen gesteld aan de uitvoering van het transport met betrekking tot betrouwbaarheid, flexibiliteit, snelheid en kosten van het transport. Bovendien hebben internationale ontwikkelingen op het gebied van regelgeving een belangrijke invloed op de concurrentiepositie van het Nederlandse wegvervoer.

De uitvoering van het feitelijke transport, het vervoeren van goederen van een plaats van oorsprong naar een plaats van bestemming, wordt aangeduid als *rituitvoering*. Het rituitvoeringsproces wordt bestuurd door een informatieverwerkend proces, *fleet* *management*. Fleet management wordt gedefinieerd als het real-time plannen, bewaken en beheersen van wagenpark-bewegingen and -activiteiten. Fleet management omvat het aannemen van binnenkomende transportorders, het toewijzen van transportorders, het onderhouden van contact met de chauffeurs, het beheersen van de rituitvoering, het eventueel wijzigen van reeds gemaakte toewijzingen en de administratieve afhandeling van uitgevoerde transportorders. De coördinatie tussen de rituitvoering en het fleet management vindt plaats door het opgeven van instructies omtrent de geplande uitvoering van transporten door de planner aan de chauffeur. De chauffeur meldt op gezette tijden de status van de huidige rituitvoering aan de planningsafdeling van het transportbedrijf.

Voor deze coördinatie wordt in de huidige situatie gebruik gemaakt van de telefoon. Dit heeft echter een aantal nadelen die worden veroorzaakt doordat het initiatief voor het maken van contact noodgedwongen bij de chauffeur ligt. Bovendien dient er een telefoon aanwezig en beschikbaar te zijn in de nabijheid van de chauffeur. Door de nadelen van het gebruik van de telefoon ontstaat een discrepantie tussen de op de planningsafdeling bekende rituitvoering en de werkelijke rituitvoering. Het bekend zijn van de werkelijke rituitvoering is van belang omdat de werkelijke rituitvoering door onvoorziene gebeurtenissen en door stochasticiteit af kan wijken van de geplande rituitvoering.

Door recente technologische ontwikkelingen op telematica-gebied is mobiele communicatie binnen het bereik van de wegvervoerder gekomen. Mobiele communicatie stelt planners en chauffeurs in staat op elk moment gedurende de rituitvoering contact met elkaar op te nemen.

Uitgangspunt voor het in deze dissertatie beschreven onderzoek is geweest dat mobiele communicatie gebruikt kan worden om het telefonisch contact tussen planners en chauffeurs te vervangen en daarmee de problemen die het gebruik van de telefoon met zich mee brengt op te lossen. Literatuuronderzoek en een proefneming om de haalbaarheid van mobiele datacommunicatie vast te stellen bevestigen deze veronderstelling. De algemene vraagstelling van het onderzoek luidt derhalve als volgt:

> *Is het mogelijk de performance van fleet management in het wegtransport te verbeteren door gebruik te maken van mobiele communicatie* ?

Uit deze algemene vraagstelling worden een drietal specifieke vraagstellingen afgeleid die respectievelijk betrekking hebben op de karakteristieken van een informatiesysteem dat gebruik maakt van mobiele communicatie voor ondersteuning van het fleet management, de performance van de taken van de planner en de performance van het rituitvoeringsproces.

Huidige situatie met betrekking tot fleet management

Een eerste afbakening die tijdens het onderzoek naar de mogelijkheden van mobiele communicatie binnen het wegtransport gemaakt wordt, is een beperking tot het analyseren van fleet management binnen het beroepsgoederenvervoer. Zij is afhankelijk van de inkomende stroom transportorders en heeft de mogelijkheid om een hogere efficiency te bereiken door de consolidatie van transportorders. Het eigen vervoer heeft deze mogelijkheden niet of slechts in beperkte mate.

Een verdere afbakening die gemaakt wordt, is het concentreren van het onderzoek op het vervoer van volledige wagenladingen, uitgebreid met een beperkte vorm van het consolideren van transportorders. Voor deze afbakening wordt gekozen omdat een groot gedeelte van de bedrijven binnen het beroepsgoederenvervoer op deze wijze transport verzorgt. Transportorders worden geacht binnen een rit geconsolideerd te kunnen worden, zolang het consolideren plaatsvindt vóór het toewijzen van het materieel aan de rit. Op deze wijze is het planningsprobleem voor het toewijzen van ritten aan materieel gelijk aan het *chauffeurs-toewijzingsprobleem*.

Voor drie transportbedrijven die binnen de gemaakte afbakening vallen wordt een analyse van de huidige situatie met betrekking tot het fleet management gemaakt. Op basis van deze drie analyses kan een algemeen beschrijvend model voor het fleet management bij transportbedrijven die binnen de gemaakte afbakening vallen worden opgesteld. Dit beschrijvend model omvat een analyse van de objecten die binnen het probleemgebied van fleet management een rol spelen, een beschrijving van de taken van de planner en een probleembeschrijving.

Fleet management start bij het binnenkomen van een verzoek van de opdrachtgever om een transportorder uit te voeren. Er wordt nagegaan of uitvoering van de transportorder economisch verantwoord is en of genoeg transportcapaciteit aanwezig is om de transportorder te kunnen uitvoeren. Indien de geaccepteerde transportorder een last-minute-order is, wordt deze direct in het ritplan opgenomen.

Het plannen van de transportorders start met het samenstellen van transportcombinaties. Een transport combinatie bestaat in ieder geval uit een chauffeur en een trekkende eenheid, met eventueel een oplegger waarop mogelijk ander materieel geplaatst wordt. Elke uit te voeren rit wordt aan één van deze transportcombinaties toegewezen en de laad- en lostijden worden bepaald. Op deze wijze wordt een *voorlopig* ritplan opgesteld. Indien er sprake is van meerdere deelladingen binnen één rit, dan worden deze geconsolideerd voordat de toewijzing van de betreffende rit aan een transportcombinatie plaatsvindt.

Nadat het voorlopige ritplan gereed is, kan geconstateerd worden of er eventueel een tekort of overschot van chauffeurs of materieel ontstaan is. Indien dit het geval is, kan de planner trachten dit tekort of overschot te elimineren door extra transportorders te verwerven, de uitvoering van transportorders uit te besteden, extra materieel in te huren of overtollig materieel tijdelijk uit te lenen.

Op het moment dat het ritplan gereed is en/of de transportcombinatie (bijna) gereed is met de uitvoering van de huidige toewijzing, dient de chauffeur van de transportcombinatie via instructies op papier of via telefonisch contact geïnformeerd te worden over de volgende uit te voeren rit.

Nadat de chauffeur de uitvoering van de ritopdracht is begonnen, meldt hij of zij regelmatig dat een bepaalde activiteit is beëindigd of dat er problemen en/of vertragingen zijn ontstaan. De planner maakt een vergelijking tussen de geplande en de werkelijke rituitvoering en beoordeelt of het noodzakelijk is om het huidige ritplan aan te passen en derhalve de opdrachtgever in te lichten. Het aanpassen van het huidige ritplan wordt uitgevoerd door het bepalen van de toewijzingen die niet meer passend zijn. Deze toewijzingen worden onderling verwisseld totdat een ritplan is verkregen dat uitvoerbaar is. Indien geen haalbaar ritplan kan worden bepaald, moet het overschot of tekort aan chauffeurs of materieel worden geëlimineerd zoals eerder beschreven is.

Naast de telefoontjes van de chauffeur dient de planner tijdens de rituitvoering ook telefoontjes van opdrachtgevers en collega-transportbedrijven te beantwoorden. Opdrachtgevers kunnen telefonisch contact opnemen om wijzigingen in de ordergegevens door te geven, om een transportorder te laten vervallen of om informatie over de ritvoortgang te vragen. Collega-transportbedrijven kunnen een verzoek doen tot het verwerven of uitbesteden van transportorders of het inhuren en uitlenen van materieel.

Nadat een rit is uitgevoerd moet deze administratief worden afgehandeld; dit houdt in dat alle documenten die op de rit betrekking hebben verzameld en opgeborgen worden, dat eventuele aan de opdrachtgever door te berekenen kosten worden gesignaleerd en dat de factuur wordt opgemaakt en verstuurd.

De belangrijkste problemen die zich bij het uitvoeren van deze taken voordoen zijn:

- De rituitvoering wordt in toenemende mate geconfronteerd met verstoringen en onverwachte gebeurtenissen. De planner is niet in staat in voldoende mate op deze gebeurtenissen te anticiperen.
- De administratieve afhandeling van ritten is tijdsintensief en heeft vaak te kampen met het ontbreken van informatie. Hierdoor wordt de facturering vaak aanzienlijk vertraagd.
- Informatie over de rituitvoering is in onvoldoende mate beschikbaar voor de betrokken planners.

- Het gebruik van de telefoon om informatie tussen de planners en chauffeurs uit te wisselen vergt veel tijd, is inefficiënt, is foutgevoelig en laat geen actieve beïnvloeding van de rituitvoering toe.
- De informatieverschaffing over de rituitvoering naar de opdrachtgever toe is onvoldoende.

Real-time fleet management

Uitgaande van de problemen die tijdens de beschrijving van de huidige situatie zijn onderkend, wordt een nadere analyse van de primaire problemen gemaakt en wordt de ondersteuning gespecificeerd die moet bijdragen tot een verbeterde uitvoering van fleet management. Deze ondersteuning bestaat uit het gebruik maken van mobiele datacommunicatie, het gestructureerd uitwisselen van informatie, het invoeren van frequente meldingen omtrent de status van de rituitvoering, mede door gebruik te maken van automatische positiebepaling, en het centraal registreren van informatie die voor de rituitvoering van belang is.

Om enerzijds te voorkomen dat de planner te veel informatie te verwerken krijgt wanneer gebruik gemaakt wordt van mobiele datacommunicatie en anderzijds om een adequate ondersteuning van het fleet management mogelijk te maken, wordt een *management-by-exception*-principe toegepast. Door een (automatische) vergelijking tussen de geplande rituitvoering en de werkelijke rituitvoering behoeft de planner slechts geïnformeerd te worden over (significante) afwijkingen die van invloed kunnen zijn op het huidige ritplan; in de overige gevallen zullen de statusmeldingen niet aan de planner worden doorgegeven.

Op basis van het toegepaste management-by-exception-principe is een layout voor een *fleet management systeem* (FMS) opgesteld. Een fleet management systeem is een op real-time informatie gebaseerde planningsondersteunende omgeving voor het real-time plannen, beheersen en bewaken van wagenparkbewegingen en -activiteiten. Binnen de layout voor een FMS zijn diverse componenten opgenomen die elk een bepaald taakgebied ondersteunen:

1. Registratie van transportorders
2. Beheer van chauffeurs en materieel
3. Ondersteuning voor het opstellen van het ritplan
4. Ondersteuning voor het aanpassen van het ritplan
5. Instrueren van chauffeurs
6. Bewaken van de rituitvoering
7. Administratieve afhandeling van ritten
8. Beheer en uitwisseling van data-berichten

Simulatie van fleet management

Het effect van het gebruik van frequente status- en positiemeldingen op de performance van de rituitvoering wordt onderzocht door middel van een simulatiemodel, ontwikkeld voor het binnen het onderzoek betrokken tanktransportbedrijf.

De rituitvoering wordt gesimuleerd door verschillende ritcomponenten te onderscheiden en voor elke ritcomponent een kansverdeling voor de duur en variantie van de ritcomponent te bepalen. Voor het bepalen van deze kansverdeling zijn daadwerkelijke gegevens gebruikt. Tevens zijn verschillende regels in het model opgenomen die bepalen wanneer een chauffeur moet gaan rusten, wanneer laad- en loslocaties geopend zijn, etc.

Het fleet management, het toewijzen van ritten aan transportcombinaties, is gesimuleerd met behulp van een heuristisch toewijzingsalgoritme. Bij het toewijzen wordt met diverse factoren rekening gehouden, zoals capaciteitsrestricties, de afstand die door de transportcombinatie moet worden afgelegd, het laadtijdstip dat door de opdrachtgever vereist wordt en de geschiktheid van het materieel om een rit uit te voeren.

Door de transportcombinatie worden op bepaalde tijdstippen statusmeldingen doorgegeven aan het fleet management. De waarschijnlijkheden en nauwkeurigheden waarmee deze meldingen worden doorgegeven zijn bepaald uit de praktijk. Nadat een statusmelding is ontvangen wordt opnieuw het tijdstip berekend waarop verwacht wordt dat de transportcombinatie gereed zal zijn met de uitvoering van de huidige opdracht. Deze verwachte eindtijdstippen worden door het toewijzingsalgoritme gebruikt bij het bepalen van een nieuwe rit voor een transportcombinatie.

Bij het gebruik van mobiele communicatie kunnen deze statusmeldingen meer frequent en met grotere waarschijnlijkheid worden doorgegeven. Uit een experiment dat is uitgevoerd is gebleken dat het gebruik van frequentere statusmeldingen leidt tot een verlaging van het aantal ritten dat niet kon worden toegewezen en een hogere effectieve snelheid. Het percentage beladen kilometers en de stiptheid van laad- en lostijdstippen daarentegen bleken niet veranderd te zijn.

Wanneer de frequentere statusmeldingen worden gebruikt om transportcombinaties kort voor aankomst op de laad- of loslocatie aan te kondigen, is de verwachting dat de laad- en losduren verkort kunnen worden. Uit een experiment met verkorte laad- en losduren is gebleken dat voor alle performance-indicatoren een significante verbetering optreedt. Alleen het percentage beladen kilometers neemt af als gevolg van de mogelijkheden die ontstaan om de stiptheid van een rit hoger te waarderen ten koste van het aantal kilometers dat eventueel als gevolg hiervan extra moet worden gereden.

Een derde experiment toont aan dat frequentere statusmeldingen geen verbetering te zien geven wanneer meer ritten met een tijdsrestrictie moeten worden uitgevoerd. Het laatste experiment dat uitgevoerd is, laat zien dat wanneer meer ritten aan het simulatiemodel worden toegevoegd, de performance van de rituitvoering tendeert te verbeteren bij het gebruik van mobiele communicatie; een significant verschil in de performance-indicatoren kan echter niet worden aangetoond.

Experimenten met een prototype fleet management systeem

Op basis van de opgestelde layout voor een FMS wordt vervolgens een prototype ontwikkeld om de haalbaarheid van de ontwikkeling van een FMS en de effecten op de uitvoering van de taken van de planner na te gaan. Dit FMS prototype heeft op een aantal punten echter een beperkte functionaliteit in vergelijking tot de eerder opgestelde layout. Het ondersteunen van het (opnieuw) toewijzen van ritten is niet geïmplementeerd. De reden hiervoor is dat geen van de bedrijven die bij het onderzoek betrokken is een voldoende groot gedeelte van het wagenpark met mobiele communicatie heeft uitgerust. Het zwaartepunt ligt derhalve op het implementeren van het management-by-exception-principe.

Voor de implementatie van het FMS prototype is gekozen voor mobiele satelliet-data-communicatie. Middels dit medium worden voorgeprogrammeerde berichten, die enerzijds ritinstructies voor de chauffeur en anderzijds statusmeldingen van de transportcombinatie kunnen bevatten, uitgewisseld tussen het FMS prototype en de chauffeurs.

Tijdens experimenten bij de drie transportbedrijven is de functionaliteit en werking van het FMS prototype beproefd. De opzet van deze experimenten is dat planners het FMS prototype daadwerkelijk gebruiken tijdens de uitvoering van hun werkzaamheden om de uitvoering van de ritten die in het FMS prototype worden opgenomen te bewaken. Aan de chauffeurs wordt de opdracht gegeven om bij het doorgeven van statusmeldingen zo veel mogelijk de voorgeprogrammeerde berichten te gebruiken zodat deze door het FMS prototype kunnen worden verwerkt.

Uit de experimenten met het FMS prototype blijkt dat het toepassen van het management-by-exception-principe door de planners als een adequate ondersteuning van hun taken met betrekking tot fleet management worden ervaren. Een FMS systeem dat gebruik maakt van dit principe levert voor bijna alle uit te voeren taken een significante tijdsbesparing en toegevoegde waarde voor de planner op. Het werken met het FMS prototype levert voor de chauffeur nog wel eens problemen op, maar deze worden als niet onoverkoombaar beschouwd.

Een analyse van de geplande en werkelijke tijdstippen waarop gebeurtenissen tijdens een rit plaatsvinden levert op dat de planner geneigd is om extra speling in het ritplan op te nemen. Mobiele communicatie kan gebruikt worden om deze speling te elimineren en zodoende de efficiency van het ritplan te vergroten.

Conclusies

Uit het uitgevoerde onderzoek kan de conclusie getrokken worden dat het mogelijk is een fleet management systeem te ontwikkelen dat in staat is de taken van de planner met betrekking tot het fleet management te ondersteunen.

De performance van de rituitvoering kan verbeterd worden door gebruik te maken van meer frequente en betrouwbare statusmeldingen, die mogelijk gemaakt worden door het invoeren van mobiele communicatie. Het blijkt echter dat grotere verbeteringen in de rituitvoering verwacht kunnen worden als gestreefd wordt naar het beter onderling afstemmen van de verschillende schakels in de logistieke keten. Dit kan bewerkstelligd worden door het aan deze schakels verschaffen van ritvoortgangs-informatie verkregen met behulp van het mobiele-communicatiesysteem.

De uitvoering van de taken van de planner kan verbeterd worden als gevolg van de invoering van een fleet management systeem. De geboden ondersteuning draagt volgens de planners op een adequate wijze bij aan de uitvoering van hun taken. Tevens wordt voor de uitvoering van de meeste functies een tijdsbesparing geconstateerd.

Als algemene conclusie kan gesteld worden dat het gebruik van mobiele communicatie de performance van het fleet management en de rituitvoering binnen een transportbedrijf kan verbeteren.

CURRICULUM VITAE

Peter Schrijver werd op 8 maart 1966 te 's-Gravenhage geboren. In 1984 behaalde hij het VWO-diploma aan het Westland College te Naaldwijk. Aan de Technische Universiteit Delft studeerde hij vervolgens informatica, alwaar in 1989 het ingenieurs-diploma behaald werd. Zijn afstudeerwerk had betrekking op het opstellen van een globaal ontwerp voor een exploitatie-informatiesysteem voor het openbaar vervoer en werd uitgevoerd bij de Koninklijke Nederlandse Vereniging van Transport-Ondernemingen (KNVTO). Vanaf september 1989 was hij werkzaam bij de Vakgroep Informatiesystemen van de Technische Universiteit Delft. In samenwerking met Koninklijk Nederlands Vervoer (KNV) is gedurende vier jaar onderzoek gedaan naar de mogelijkheden van het toepassen van mobiele communicatie binnen het wegtransport. Tijdens deze periode zijn diverse, mede door de overheid gesubsidieerde, projecten ten behoeve van het stimuleren van mobiele communicatie binnen het wegtransport uitgevoerd. Verder is hij betrokken geweest bij de begeleiding van diverse afstudeerders, met name op het raakvlak van informatiesystemen en vervoer. Gedurende de uitvoering van het promotie-onderzoek zijn diverse presentaties gehouden op conferenties in Nederland, België, Duitsland, Frankrijk en de Verenigde Staten.